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The effect of spark arresters upon the flow of gases in a chimney

Harold Douglas White
Iowa State College

THE EFFECT OF SPARK ARRESTERS UPON THE FLOW OF GASES IN A CHIMNEY

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Harold D. White

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Approved:

Henry Giese
In charge of Major work

J. B. Davidson
Head of Major Department

R. E. Buchanan
Dean of Graduate College

Iowa State College

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INTRODUCTION

During the period of years 1930-36, inclusive, an average of 2,192 rural fires per year were reported in Iowa; 398.9 of these fires were caused by sparks on combustible roofs. The belief that a large number of the rural fires is preventable has increased the demand for spark arresters, a simple device which may be installed on a chimney to prevent the escape of dangerous soot particles.

The increased use of spark arresters has brought about the demand for an efficient spark arrester which would not be prohibitive in cost to any home owner and has led to the manufacture of spark arresters upon a commercial basis.

With the introduction of the domestic spark arrester on a commercial basis, insurance companies have become interested in the possibilities of preventing a large portion of their losses by the use of this simple device. The Iowa Farmers Mutual Reinsurance Association of Grinnell, Iowa, installed during the years 1935-37, inclusive, 8,833 arresters on 24,045 risks inspected in 39 counties in Iowa.

The large number of spark arresters which have been placed in use has brought about the demand for the following information: (a) How will spark arresters affect the performance of a chimney? (b) Under what conditions will a spark arrester affect the performance of a chimney? The lack of specific information on the two questions is general. The only knowledge of the subject is in the form of verbal expressions of opinions by those who have observed the clogging of spark arresters after they have been placed in use.

The purpose of the investigation was: (a) To study the effect of partially clogged and completely clogged spark arresters upon the flow of air in a model chimney, and (b) to study the effect of partially clogged and completely clogged spark arresters upon the flow of gases in a natural draft chimney.

HISTORICAL

The Project

This study is a part of the general project of the Agricultural Engineering Experiment Station, "An Investigation of the Wind and Fire Losses to Farm Buildings in Iowa." The objects of this division of the project is to make a study of fire losses resulting from sparks on combustible roofs and to determine the effect of spark arresters upon the flow of gases in a chimney.

The work has been pursued in three different fields of activity. Briefly, they may be stated as follows:

1. Statistical study of rural fires resulting from sparks on combustible roofs in Iowa.
2. Field observation of spark arresters which have been in use for several years.
3. Laboratory study.

The statistical study was undertaken in an effort to obtain additional information regarding the magnitude of rural fire loss caused by sparks on roofs in Iowa.

A field study of spark arresters which have been in use for several years was necessary in order to gain a clear understanding of the characteristics of the arresters after they have been in use and to become familiar with some of the problems with which Insurance Inspectors are confronted when they attempt to install a spark arrester on the farmer's house which is covered with badly weathered wood shingles.

The laboratory work consisted of a detailed study of the effect of conventional type spark arresters upon the pressure and velocity of air in model chimneys, a study of the characteristics of natural draft chimneys operating under normal conditions and testing the influence of clogged spark arresters upon the flow of gases in a natural draft chimney.

Review of Literature

An analysis of Iowa's rural fire loss for 1930-1931 was effectively treated by Anderson (3). The study revealed the fact that of the known causes of rural fires, sparks on combustible roofs caused the greatest number of fires. Defective flues and sparks on roof caused about the same amount of damage but sparks on roof caused twice as many fires.

Peikert (13) was the first to report work dealing directly with spark arresters and their control of roof fires. His work was preceded by a brief statistical study of rural fires in Iowa and the work reported verified the previous statement that sparks on roof cause the greatest number of fires. Peikert stated that the most promising point of attack in reducing this item of loss is to break up shimney sparks into fragments sufficiently small to prevent the chance of ignition and that this could be accomplished by means of a spark arrester. Tests were reported on the susceptibility of arresters to clogging and it was concluded that with the use of certain fuels some degree of clogging could be expected with all of the arresters tested.

The requirements of a good spark arrester were stated by Peikert (13) as follows:

1. "Present a maximum of protection against the release of large live sparks from the chimney."
2. "Remain reasonably free from soot and other obstructions over an extended period of use."
3. "Admit of easy cleaning should clogging occur."
4. "Not interfere with the natural draft of the chimney."
5. "Be made of a material which will be durable for a reasonable period of time."

A variety of tests on the efficiency of spark arresters in controlling roof fires has been reported by Lanham (8) Peach (12) and Test (16).

Lanham (8) was the first to report tests on the effect of spark arresters upon the movement of air currents within a chimney. In his tests Lanham forced air through an opening in the base of a chimney, then measured the effect of different types of spark arresters upon the velocity of the air by means of a vane anemometer located 2 1/2 feet below the top of the chimney. The open top arresters exhibited the least tendency to reduce the velocity of the air currents in the flue.

No work has been reported on the effect of clogged spark arresters upon the flow of gases in a chimney. The lack of available information on the subject has prompted this investigation. Information is available on chimney construction, chimney characteristics and on some of the factors which influence the performance of a chimney. An understanding of some of the factors and characteristics will enable one to become more closely associated with the problems involved. To a certain degree this can be accomplished by a review of some literature on the subject of draft and chimney characteristics.

The American Society of Heating and Ventilating Engineers (1) have devoted a chapter, in their Guide for 1937, to a discussion of "Chimneys and draft calculations." The following statements have been incorporated in the chapter:

"The design and construction of a chimney is so important a part of the heating engineer's work that a general knowledge of draft characteristics and calculations is essential.

"Draft, in general, may be defined as the pressure difference between the atmospheric pressure and that at any part of an installation through which the gases flow. Since a pressure difference implies a head, draft is a static force. While no element of motion is inferred, yet motion in the form of circulation of gases throughout an entire boiler plant installation is the direct result of draft. This motion is due to the pressure difference, or unbalanced pressure, which compels the gases to flow. Draft is often classified into two kinds according to whether it is created thermally or artificially, (1) natural draft or thermal draft, and (2) artificial or mechanical draft.

"Natural draft is the difference in pressure produced by the difference in weight between the relatively hot gases inside a natural draft chimney and an equivalent column of the cooler outside air, or atmosphere. Natural draft in other words, is an unbalanced pressure produced thermally by a natural draft chimney as the pressure transformer and a temperature difference. The intensity of natural draft depends, for the most part, upon the height of the chimney above the grate bar level and also the temperature differnce between the chimney gases and the atmosphere.

"A natural draft chimney performs a two-fold service of assisting in the creation of draft by aspiration and also of discharging the gases at an elevation sufficient to prevent them from becoming a nuisance." p. 463.

Mingle (9) in his book on "Draft and Capacity of Chimneys," has the following to say regarding natural draft:

"Natural draft is the difference in pressure, or difference in head, or the pressure difference produced by the difference in weight between the hot air or gases inside the chimney and an equal column of outside air.

"Natural draft, then, is produced thermally by creating a difference in temperature between the gases inside the chimney and the outside air, thereby creating a difference in pressure which causes a flow or circulation. Natural draft is, in effect a form of induced draft in that it causes the air to be supplied to the fuel bed by means of a suction.

"Natural draft seems to be a difficult subject to comprehend and numerous analogies have been worked out to aid in a clear understanding of the manner in which it acts. The primary purpose of the chimney is a container in which to destroy equilibrium and thereby effect a difference in pressure which, in turn, causes the gases to flow. Natural draft then, in short, is the difference in pressure as produced by a chimney and a difference in temperature available for the flow of gases.

"The chimney may also be regarded as a vertical heat engine whose function is to pump air into the fuel bed and gases through the rest of the installation and then discharge them from its top.

"Much of the misunderstanding of the natural draft doubtless comes from the use of such common expressions as 'sitting in a draft,' 'closing the draft in a furnace,' etc. Inasmuch as natural draft is a static force, such expressions are manifestly wrong. The direct result of draft, however it may be produced, is a current of air or gases as the case may be. Winds are currents of air and are the results of a draft on an immensely large scale. The warmer air next to the surface of the earth has a tendency to rise and the cooler air, being denser, descends and tends to supplant the former. This results in gigantic movements of air called winds. When we sit near an open window and the wind blows on us we are not sitting in a draft but in a current of air or something which is the result of a draft. Again in reference to the furnace, we do not shut off the draft but shut off the air supply and therefore throttle the circulation. As a matter of fact the draft is greater when the air inlets are closed than when they are open, due to the fact that there is no circulation of gases and therefore no friction. The result of natural draft when there is an air inlet at the bottom of the chimney is a current of gases going up the chimney. It is this current of gases that is often mistaken for draft. This current of gases determines the capacity of the chimney and has nothing to do with the production of draft.

"Another misconception commonly encountered is that maximum draft refers to the maximum volume or weight of chimney gases moved in a chimney. This idea also is erroneous. Maximum draft is the maximum difference in pressure and is dependent upon the temperature of the chimney gases and the height of the chimney, while the maximum capacity is the total amount of gases a chimney is capable of moving and is dependent upon the temperature of the chimney gases and also upon the amount of air admitted for combustion. The draft of a chimney increases as long as the temperature of the chimney gases increases but the capacity of a chimney increases as the temperature of the chimney gases increases only up to about 600 degrees Fahrenheit, after which the capacity actually decreases as the temperature of the chimney gases increases. As a matter of fact the maximum draft of a chimney is obtained when the complete installation is practically air-tight and no air is admitted to the fire." p. 13-21.

Natural draft as used in this manuscript has been given the American Society of Heating and Ventilating Engineer's (1) interpretation - the difference in pressure produced by a difference in weight between the relatively hot gases inside a natural draft chimney and an equivalent column of the cooler outside air, or atmosphere.

Kratz (7) has the following to say in discussing the "Use of the Draft Gauge for Testing Chimneys in Warm Air Heating Plants":

"It is probable that no one factor governing the installation of warm air furnaces gives the installer more concern than the question of whether or not an adequate chimney has been provided. In this respect, he is more or less at the mercy of the architect, or contractor, or of both, and must make the best of the chimney which has been built without taking him into consideration. If the furnace smokes, or fails to develop the required capacity, the case is usually argued on the basis of the personal opinions and experiences of the parties concerned. This basis of settlement often leaves one or other of the parties more or less unconvinced, and the owner is apt to be the ultimate sufferer. It is, therefore, highly desirable that some means be used whereby the case is taken out of the realm of personal opinion, and settled on the basis of accurate measurements made to determine the actual performance of the chimney in question."

Kratz (7) lists the common causes of poor draft as: (1) Cooling of the chimney gases, (2) excessive friction, (3) wind effects, (4) insufficient height.

"If the top of the chimney is not carried well above the ridge of the roof, the wind may be directed over the top in such a manner that a back draft is produced, thus destroying the draft. Trees or other objects located near the chimney may also produce this effect.

"Any one of the defects enumerated may be insufficient to interfere very seriously with the action of the chimney, and where trouble is encountered it is usually caused by a combination of factors. In any case, the proper method of procedure is first to measure the draft by means of a draft gauge. This gives very definite proof that the chimney either is or is not defective. When such proof is obtained, the remedy may then be found by a thorough examination and by the process of elimination, taking account of various possible defects which have been enumerated and listed."

A discussion of the characteristics of chimneys is given by the A. S. H. V. E. Guide (1). The general operating characteristics of the chimney are compared with those of a centrifugel pump and also of a centrifugally-induced draft fan. A statement is made that the draft-capacity curve of the chimney corresponds to the head-capacity curve of the pump and also to the dynamic-head capacity curve of the fan. p. 465.

The Guide also summarized the advantages and disadvantages of a natural draft chimney. The advantages are:

1. Simplicity
2. Reliability
3. Freedom from mechanical parts
4. Low cost of maintenance
5. Relatively long life
6. Relatively low depreciation
7. No cost required to operate

The principal disadvantages are:

1. Lack of flexibility
2. Irregularity
3. Affected by surroundings
4. Affected by temperature changes p. 464.

The draft required to effect a given rate of burning the fuel as measured at the smokehood is dependent on the following factors: (1)

1. "Kind and size of fuel
2. Combustion rate per square foot of grate area per hour
3. Thickness of fuel bed

4. Type and amount of ash and clinker accumulation
5. Amount of excess air present in the gases
6. Resistance offered by the boiler passes to the flow of gases
7. Accumulation of soot in the passes"

"Insufficient draft will necessitate additional manipulation of the fuel bed and more frequent cleanings to keep its resistance down. Insufficient draft also restricts the control by adjustment of the dampers."

"The quantity of excess air present has a marked effect on the draft required to produce a given rate of burning, and it is often possible to produce a higher rate by increasing the thickness of the fuel bed." p. 487.

In a bulletin (2) released by the United States Department of Agriculture a number of common faults in chimney construction were listed; among them were the following:

"Lack of a tight flue. A flue free from leakage is unusual. Every flue should be tight enough to prevent the escape of smoke. A leaky flue is the most frequent cause of heating troubles, high fuel bills, and destructive fires."

"The top of the chimney should extend at least 3 feet above flat roofs and 2 feet above the ridge of peak roofs, and it should not be on the side of the house adjacent to a large tree or a structure higher than itself for these may cause eddies and force air down the chimney."

James Stanworth (15) in his book "Smoky Chimneys and the Study of Air Currents" has the following to say about chimneys:

"Amongst the many branches of the building trade, which are dealt with by the various works large and small, on Building Construction, I find that the subjects of chimneys and flues, are very inadequately explained. I myself, have for years been in search of information on the subject. I have discussed these matters with other people in the trade and I find this lack of knowledge general. Most people look on smoky chimneys as something which cannot be foreseen or cured, and which must be endured. The trouble is, of course, that builders and architects are not usually scientists, neither are scientists builders, and the combined knowledge is required for the proper understanding of the action of chimneys." (Preface)

Stanworth discussed the flow of gases in a chimney and states:

"When a fluid issues from any opening it is found that due to eddy currents and friction, the stream has a sectional area less than that of the opening. The relative size varies with the velocity of the fluid, but for air it is found by experiment that the stream has .65 of the sectional area of the opening. In order to produce smooth flow, it is advisable to use a chimney-pot, tapered to a sectional area of about .65 of the narrowest portion of the flue. In most modern fires this is least at the throat just above the fire, and varies from about 80 to 100 square inches. Such a chimney pot will produce smooth flow with the greatest velocity. The chimney is most efficient, however, when the gases enter the air with the least velocity, because then the pressure is greatest. The effect may be produced by making the pot diverging in the upper portion." p. 7.

In discussing the factors which may interfere with the performance of a chimney Stanworth (15) states that in one way or other, winds are the cause of at least 90 per cent of smoky chimneys. p. 13.

Test (16) in his investigation concluded that a maximum temperature of 1500 degrees could be expected in the chimney for the average dwelling. This occurs only under burn out conditions. Calculations were made for the theoretical maximum velocity attained by the rising flue gases in a chimney whose diameter is 0.8 foot. The maximum velocity will occur when there is a maximum temperature in the chimney. The maximum velocity, in round figures, was found to be 740 feet per minute.

ANALYSIS OF THE PROBLEM

Statistical Study of Rural Fire Losses in Iowa

The reason why spark arresters are and should be used on chimneys will be discussed briefly by reviewing the rural fire losses reported in Iowa for the years 1930 to 1936, inclusive. The fire data reported were taken from the records in the State Fire Marshal's office in Des Moines.

Known causes of rural dwelling fires

Figure 1 shows the comparative significance of the known causes of rural dwelling fires for the 7 year average, 1930-26, inclusive. The number of fires caused by sparks on roof is very significant and even though defective flues caused slightly more damage than fires from sparks on roof, the number of roof fires which occur might cause even greater damage if they were not discovered in time.

Rural fire loss from sparks on roof

The number of fires as well as the amount of loss resulting from sparks on roof for the 7 year period, 1930-36, is shown in Table 1. From the table it is possible to get some idea of the distribution of roof fires by town and country

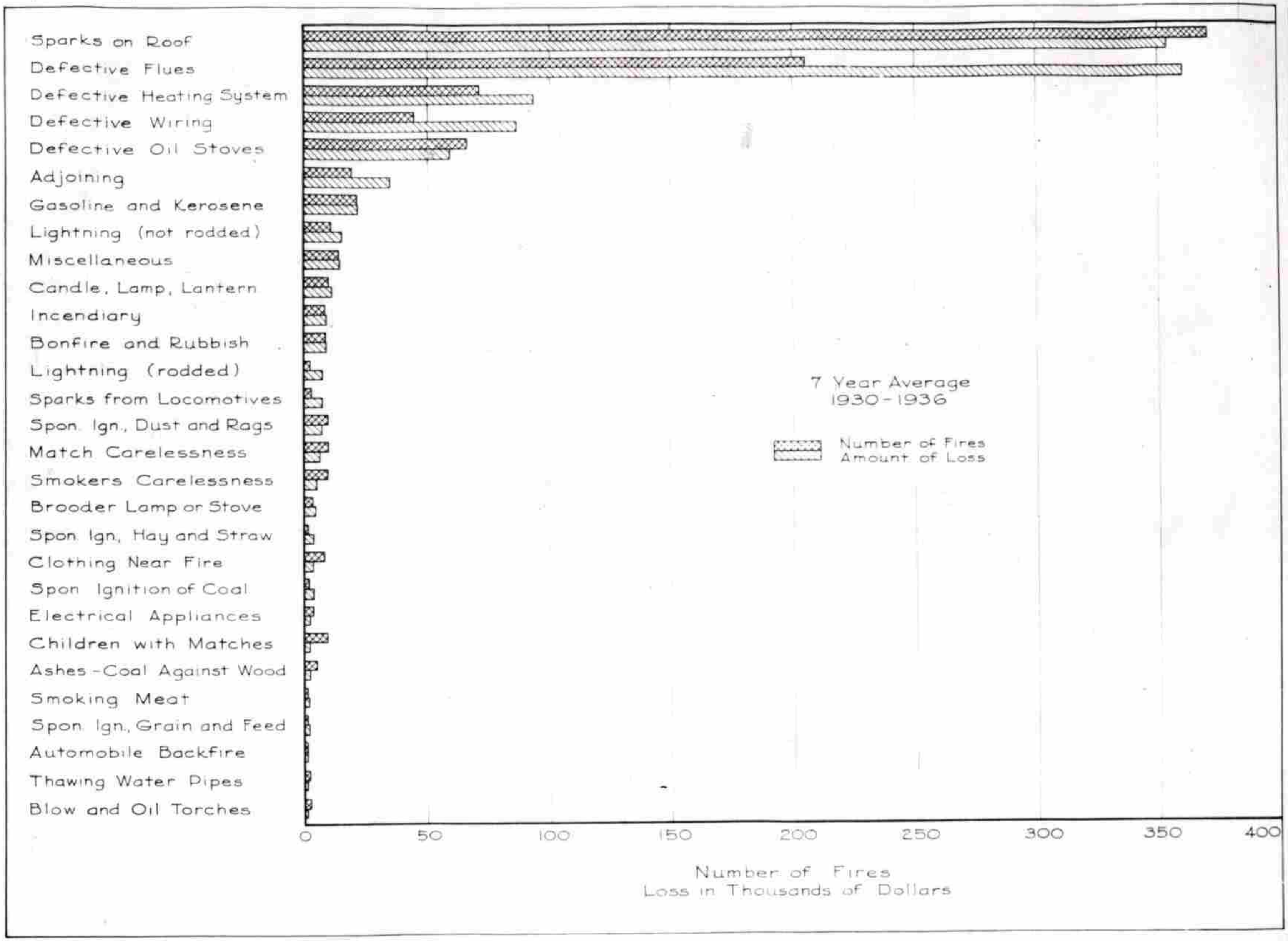


FIG. 1. KNOWN CAUSES OF DWELLING FIRES

TABLE 1

Rural Fire Losses Due to Sparks on Roof 1930-36 and 7 Yr. Average

Year	Rural		Country				Town			
	Number of Fires	Amount of Loss	No. of Fires	% of Rural Fires	Amount of Loss	% of Rural Loss	Number of Fires	% of Rural Fires	Amount of Loss	% of Rural Loss
1930	491	$ 451,261	164	33.4	$ 360,394	79.9	327	66.6	$ 90,867	20.1
1931	422	497,132	151	35.8	395,165	79.5	271	64.2	101,967	20.5
1932	415	406,697	139	33.5	316,804	77.9	276	66.5	89,893	22.1
1933	401	304,067	124	30.9	230,858	75.9	277	69.1	73,209	24.1
1934	451	422,995	185	41.0	347,573	82.2	266	59.0	75,422	17.8
1935	243	200,733	86	35.4	170,852	85.1	157	64.6	29,881	14.9
1936	369	347,593	144	39.0	272,038	78.3	225	61.0	75,555	21.7
Total	2,792	2,630,478	993	35.6	2,093,684	79.6	1,799	64.4	536,794	20.4
Average	398.9	375,782.57	141.9		299,097.71		257.0		76,684.86	

losses. The average country loss per year amounts to $299,097.71 for only 141.9 fires, while the town loss only amounted to $76,684.86 for 257.0 fires. This tremendous difference in loss may be attributed to the fact that country fires usually burn to completion.

The rural fire waste caused by sparks on roof is compared with the total rural fire waste in Table 2. Sparks on roof caused 18.2 per cent of the total number of rural fires.

Desirability of Spark Arresters

In an effort to reduce the number of rural fires caused by sparks on roof, considerable attention has been directed toward spark arresters. The desirability of a spark arrester can best be appreciated by a study of the position that chimney sparks hold among the causes of rural fires. Figure 2 shows a typical roof fire tragedy.

The roof fire problem could be solved by the use of non-combustible roofing material; however, there are in every community wooden shingle roofs which are still serviceable but which present a real fire hazard. Under such conditions spark arresters have real possibilities. Figure 3 shows a spark arrester of early design.

TABLE 2

Rural Fire Loss Caused by Sparks on Roof

Compared with Total Rural Fire Loss

	Total Rural Fire Loss		Rural Fires Caused by Sparks on Roof			
Year	No. of Fires	Amount of Loss	No. of Fires	% of Total Rural Fires	Amount of Loss	% of Total Rural Loss
1930	2,666	$ 4,981,612	491	18.4	$ 451,261	9.1
1931	2,247	4,332,268	422	18.8	497,132	11.5
1932	2,457	4,178,794	415	16.9	406,697	9.7
1933	2,059	3,026,146	401	19.5	304,067	10.0
1934	2,163	2,688,145	451	20.8	422,995	15.7
1935	1,327	1,710,294	243	18.3	200,733	11.7
1936	2,425	4,390,015	369	15.2	347,593	7.9
Total	15,344	25,307,274	2,792	18.2	2,630,478	10.4
Average	2,192	3,615,324.8	398.9		375,782.57	

Fig. 2. Typical Roof Fire Tragedy

Fig. 3. Spark Arrester of Early Design

Requirements of Spark Arresters

In order to successfully perform the job for which it was designed, a spark arrester would only have to prevent the escape of dangerous soot particles from a chimney; however, there are other factors which are of importance to the users of spark arresters. First, the arrester should not interfere with the performance of the chimney; second, the arrester should be of reasonably low cost.

The efficiency of domestic spark arresters has been discussed by Giese (5) and the fact that spark arresters are available at low cost has encouraged insurance companies to install spark arresters on most of their risks insured. During 1935-37, inclusive, the Iowa Farmers Mutual Reinsurance Association of Grinnell installed 8,833 spark arresters on 24,045 risks inspected.

The lack of information on the subject as to how much and under what conditions spark arresters interfere with the performance of a chimney has prompted this investigation.

EXPERIMENTAL

Aims of the Investigation

Despite the fact that spark arresters are designed and sold on the market, very little is known as to how much resistance they offer to the flow of air, and no information is available as to how much they will interfere with the performance of a natural draft chimney.

This part of the investigation will be discussed in two parts, the aims of which are as follows:

1. To determine the effect of partially clogged and completely clogged spark arresters upon the flow of air in model chimneys

2. To determine the effect of partially clogged and completely clogged spark arresters upon the flow of gases in a natural draft chimney

The Effect of Spark Arresters upon the Flow of Air Through Model Chimneys

Introduction

The fact that spark arresters do under certain conditions interfere with the performance of a chimney presents a real problem of selecting a suitable testing procedure. The testing procedure should yield reliable data despite the large number of variables to be taken into consideration. In thinking of a possible way to test the arresters it was decided to use a model chimney and blower. By the use of forced draft a large number of variables would be eliminated; however, the conditions which exist in a chimney would not be exactly duplicated. In a model chimney equipped with a blower the difference in pressure produced is above atmospheric pressure, whereas in a natural draft chimney which is operating under normal conditions, the difference in pressure is produced by a difference in weight between the gases inside the chimney and an equal column of outside air, and the pressure inside the chimney is less than atmospheric pressure. A further comparison of the tests would be that a maximum positive pressure is produced at the bottom of the model chimney, and in the natural draft chimney there is a maximum negative draft produced at the bottom of the chimney. Even though there is this difference in pressures, the two will approach atmospheric pressure near the top of the chimney, and the resistance offered by the arresters to the flow of air should be representative of the resistance offered to the flow of gases.

Objectives of the investigation

The objectives of this part of the investigation may be briefly stated as follows:

1. To determine the effect of spark arresters upon the flow of air through a small model chimney

2. To determine the effect of spark arresters upon the flow of air through a large model chimney

3. To determine the effect of different size and location of baffle in a number 3 spark arrester upon the flow of air through a large model chimney

Model chimneys. A small model chimney shown in Figure 4 was available in the Agricultural Engineering Laboratory. A sectional sketch of this model chimney is shown by Figure 6. The chimney was 11 5/8" x 11 1/2" at the base and tapered to 8 1/2" x 12 1/2" at the top. The flat metal flanges on the top of the chimney offered sufficient support for the spark arresters.

A partially clogged spark arrester, Figure 5, is typical of the type of arresters used in the first part of this investigation.

A large model chimney was constructed according to the sectional sketch, Figure 7. The chimney was 11 5/8" x 11 1/2" at the base and tapered to 8 1/2" x 12 1/2" in 21". The chimney had a uniform cross section for a height of 8'-3". The openings in the side were located as shown on the drawings and the number of the openings corresponds to the pressure readings at these points recorded in the tables.

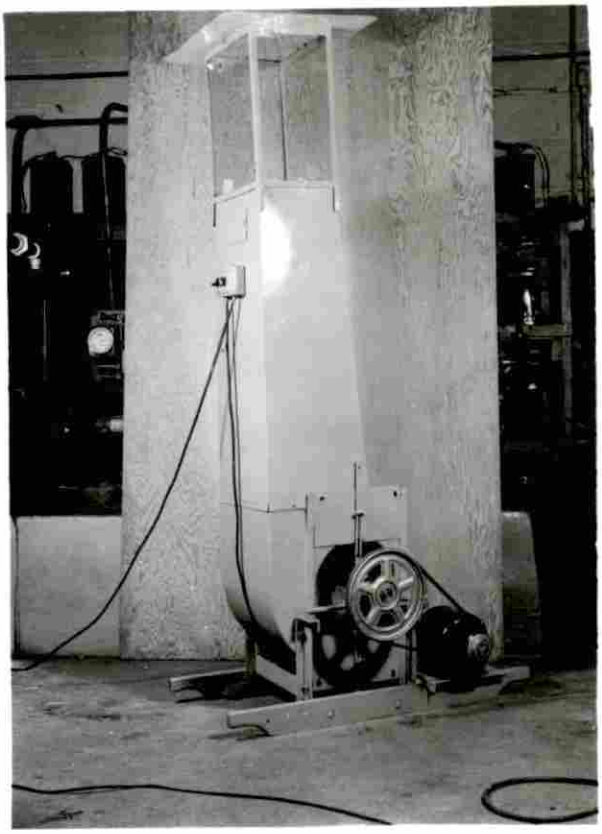


Fig. 4. Small Model Chimney and Blower

Fig. 5. Typical Partially Clogged Spark Arrester

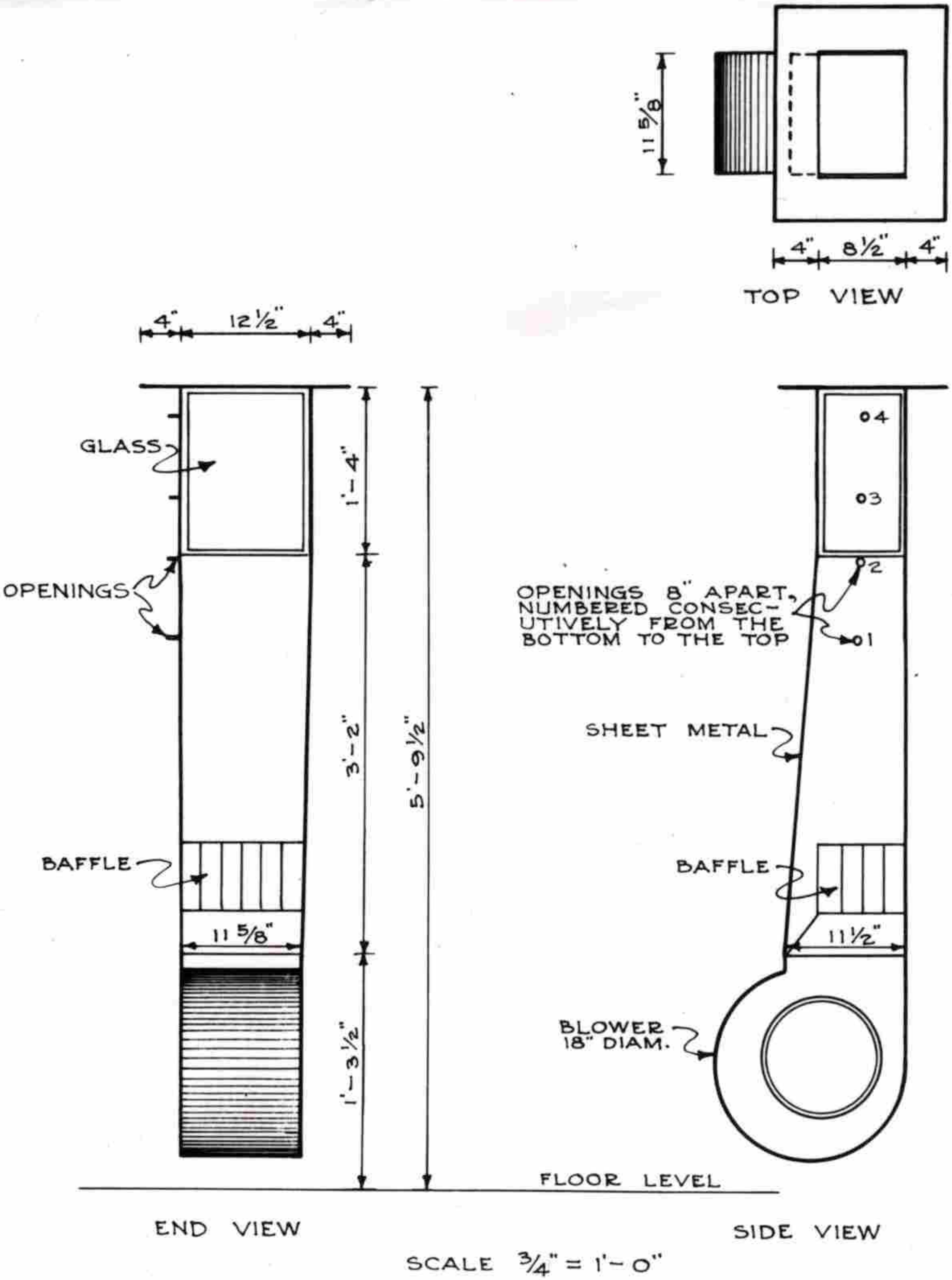


Fig. 6. SECTIONAL SKETCH OF MODEL CHIMNEY NO. 1

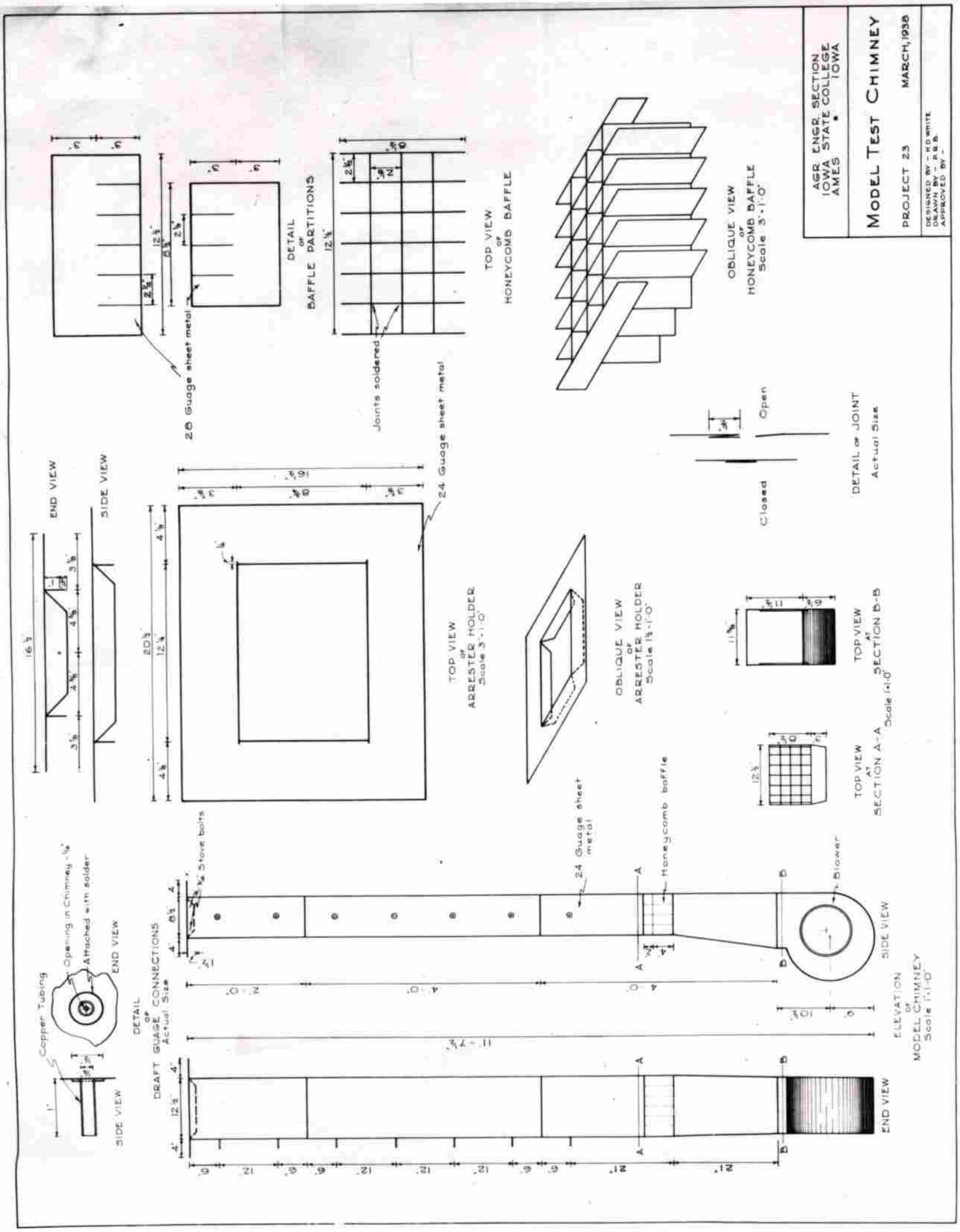


Fig. 7. Sectional Sketch of Model Chimney No. 2

Figure 9 shows the large chimney with spark arrester in place ready for test. The model chimney dismantled by sections is shown by Figure 8. By use of different sections or by adding new sections the height of the chimney could be varied.

Blower. A 10-inch multiblade furnace blower as manufactured by The Lennox Furnace Company, Inc., Marshalltown, Iowa, was used to furnish the blast of air for this investigation. The blower was powered by a quarter horse power General Electric motor. The fan was arranged to discharge vertically as shown in Figure 8.

Adjustable shutters made it possible to regulate the intake of the blower and thereby change the velocity of the air in the chimney. A detail of the intake shutter assembly is shown in Figure 10.

Draft gauge. Two draft gauges were used in connection with this part of the investigation. A number 1-DL-1 draft gauge with a scale range of 0 to -.1 of an inch of water and a dry type B portable draft gauge with a scale range of 0 to 2 and 0 to -2.0 inches of water was used, depending upon the range of pressure encountered. Both gauges were manufactured by the Hays Corporation, Michigan City, Indiana. The 1-DL-1 gauge could be adjusted to take positive readings up to .02 inch of water but performed much better if used only to detect negative differences in pressure.

Connection from the draft gauge to the chimney was made

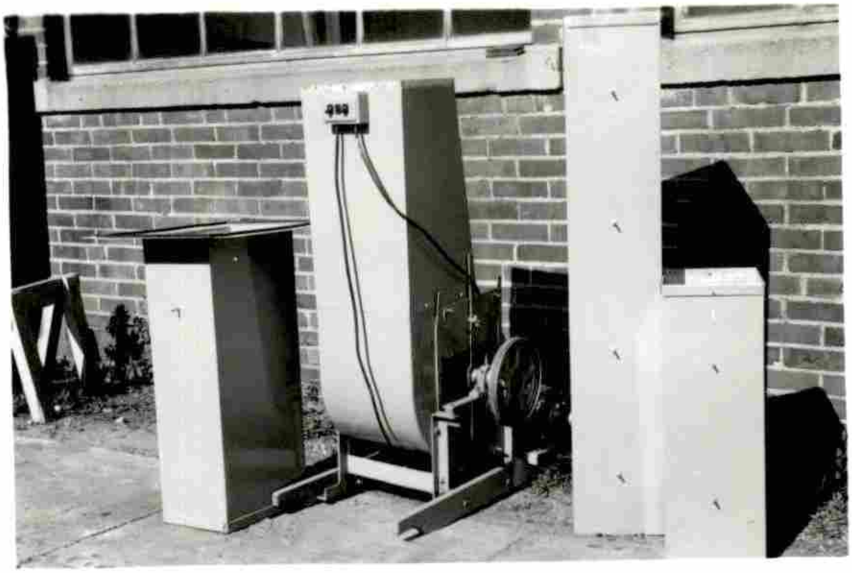


Fig. 8. Model Chimney Dismantled by Sections

Fig. 9. Large Model Chimney No. 2 with Draft Gauge Connections and Arrester in Place Ready for Test

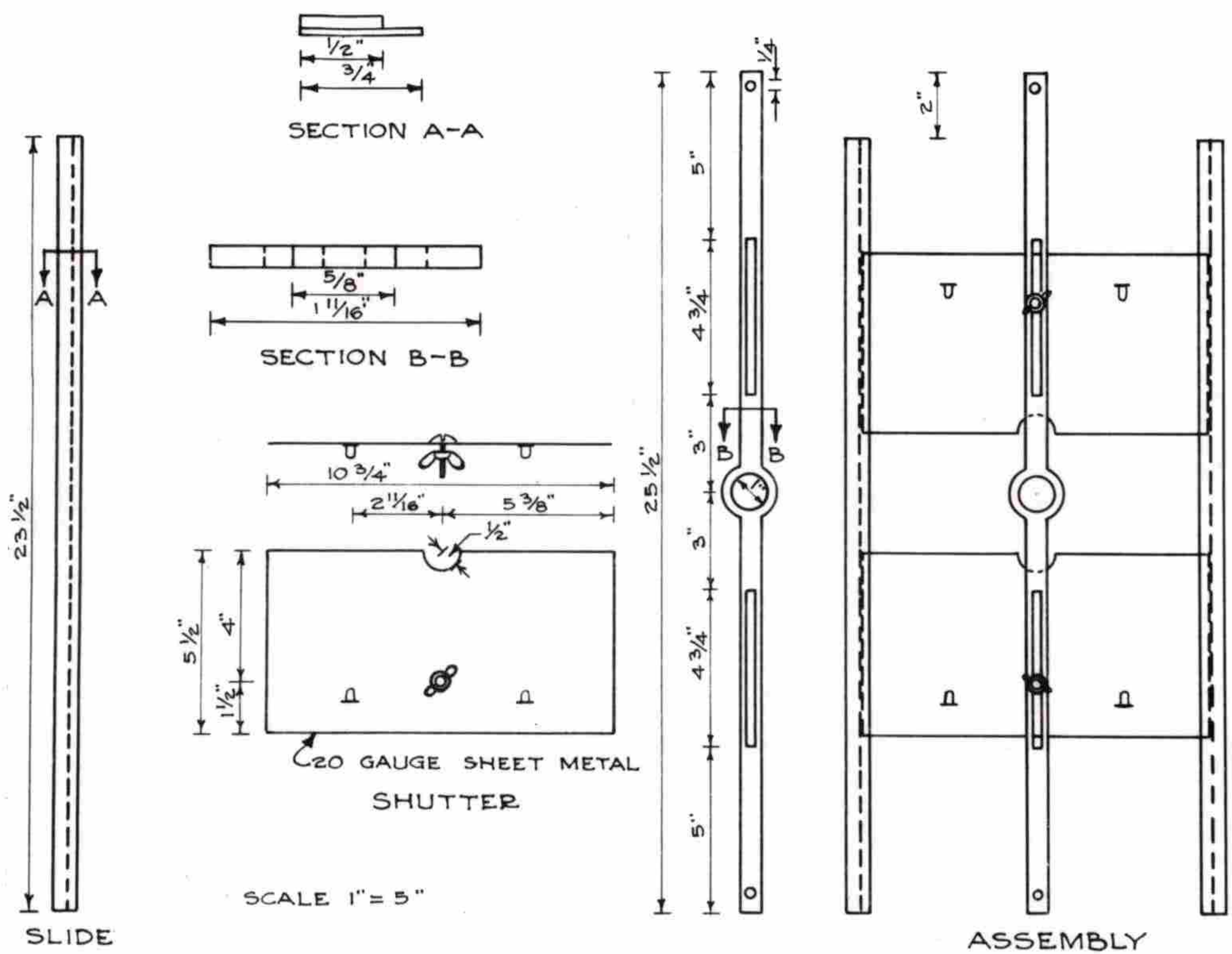


Fig. 10. INTAKE SHUTTER ASSEMBLY FOR BLOWER

by means of 1/8-inch rubber tubes. A multiple draft gauge connection shown in Figure 9 made it possible to take readings at any one of the different locations in the chimney by merely opening a stopcock.

Velometer. An Alnor (Boyle System) velometer as manufactured by the Illinois Testing Laboratories, Inc., Chicago, was used to measure the velocity of the air flowing through the chimney. The instrument has two scale ranges: a low range of 0 - 250 and a high range of 0 - 2500 feet per minute. All of the readings taken in this investigation were on the high range and with a jet type number 2425-18. The instrument was designed to take intermittent readings of very short duration in temperatures as high as 1000 degrees Fahrenheit. The accuracy of the readings was within 3 per cent of full scale reading. The draft gauge, velometer and spark arrester in place ready for test are shown in Figure 11.

Honey-comb baffle. The baffle which was inserted in the model chimney is shown by Figure 12. The baffle tended to straighten out the air currents and produce straight-line flow of the air.

Spark arresters used in the investigation. An effort was made to select representative styles of domestic spark arresters for testing purposes throughout the work as reported in this manuscript. The spark arresters selected are as follows:

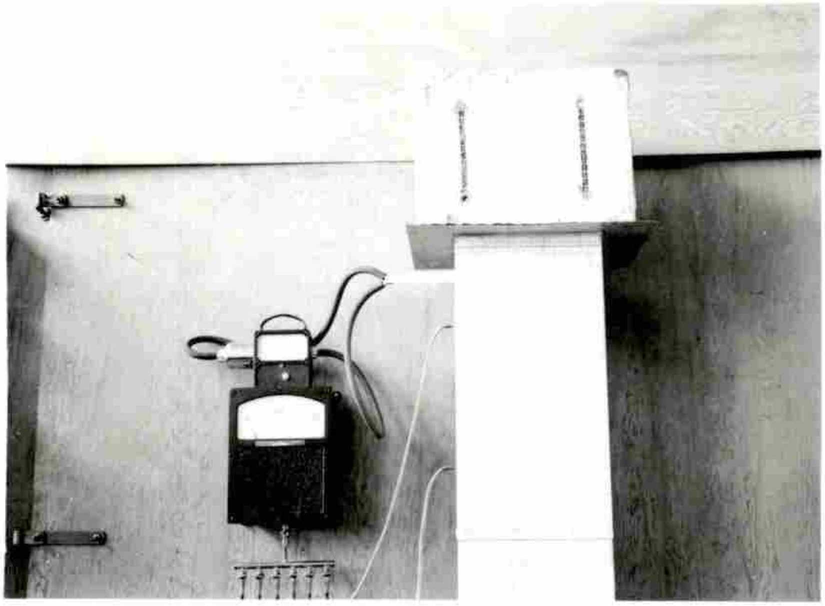


Fig. 11. Arrester in Place on Chimney with Velometer and Draft Gauge Ready for Test

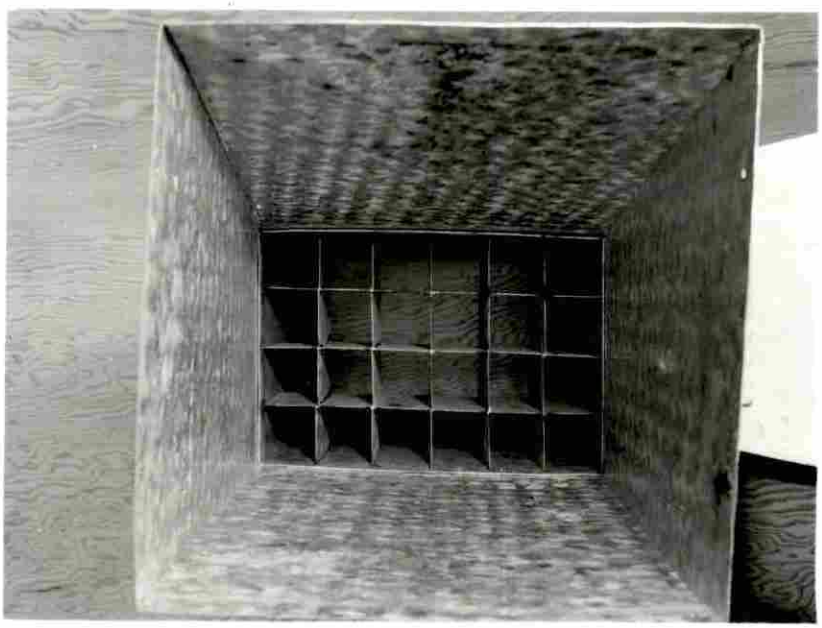


Fig. 12. Interior of Model Chimney Showing Honeycomb Baffle

Number 1

National Open Top, Type A Spark Arrester

Manufactured by: National Supply and Service Corp.
Crawfordsville, Indiana

Figure 13

Number 2

National Open Top, Type B Spark Arrester

Manufactured by: National Supply and Service Corp.
Crawfordsville, Indiana

Figure 14

Number 3

Mutual #2 Spark Arrester

Manufactured by: The Farmers Mutual Reinsurance
Association, Grinnell, Iowa

Figure 15

Number 4

Mutual #1 Spark Arrester

Manufactured by: The Farmers Mutual Reinsurance
Association, Grinnell, Iowa

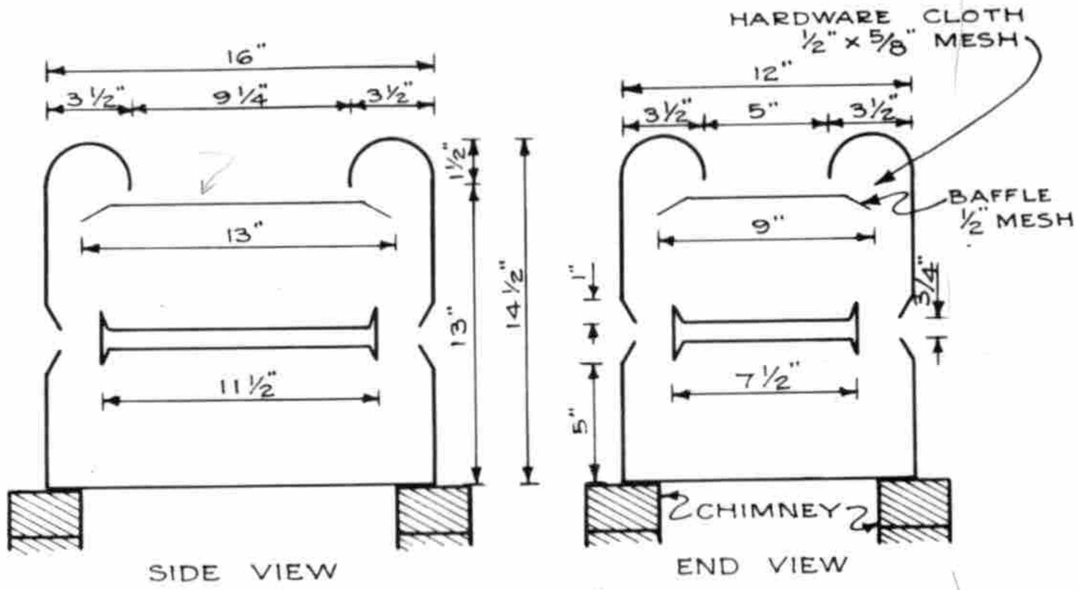
Figure 16

Number 5

National Closed Top Spark Arrester

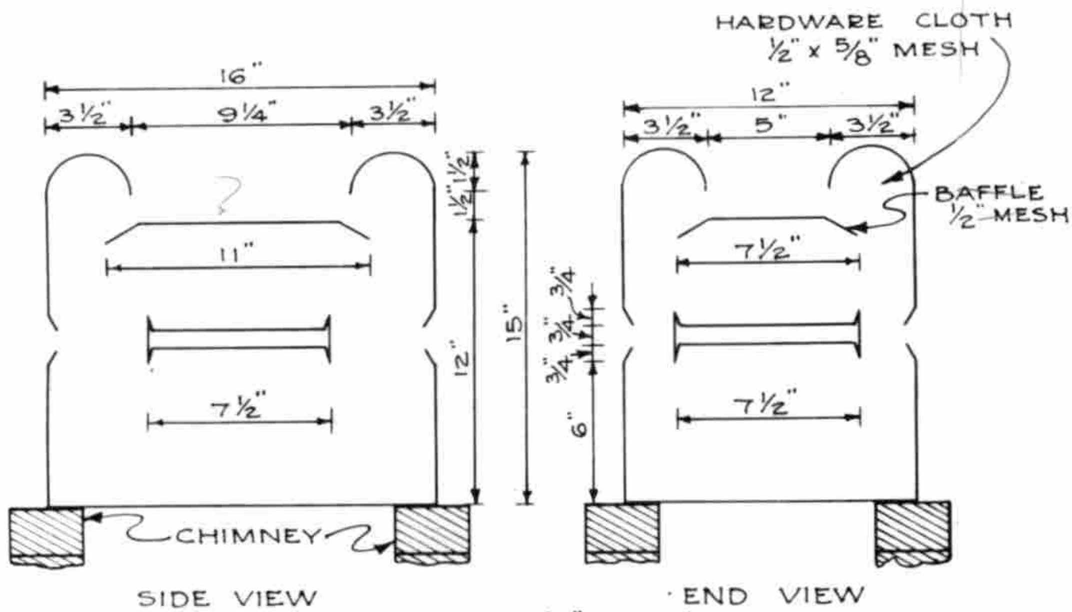
Manufactured by: National Supply and Service Corp.
Crawfordsville, Indiana

Figure 17



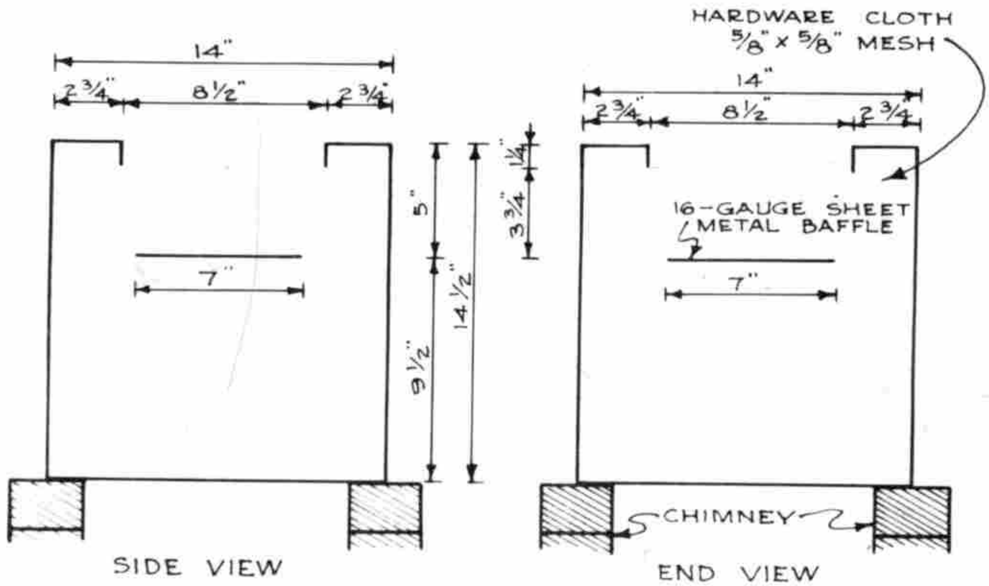
SCALE 1½" = 1'-0"

Fig. 13. SECTIONAL SKETCH OF NO. 1 SPARK ARRESTER



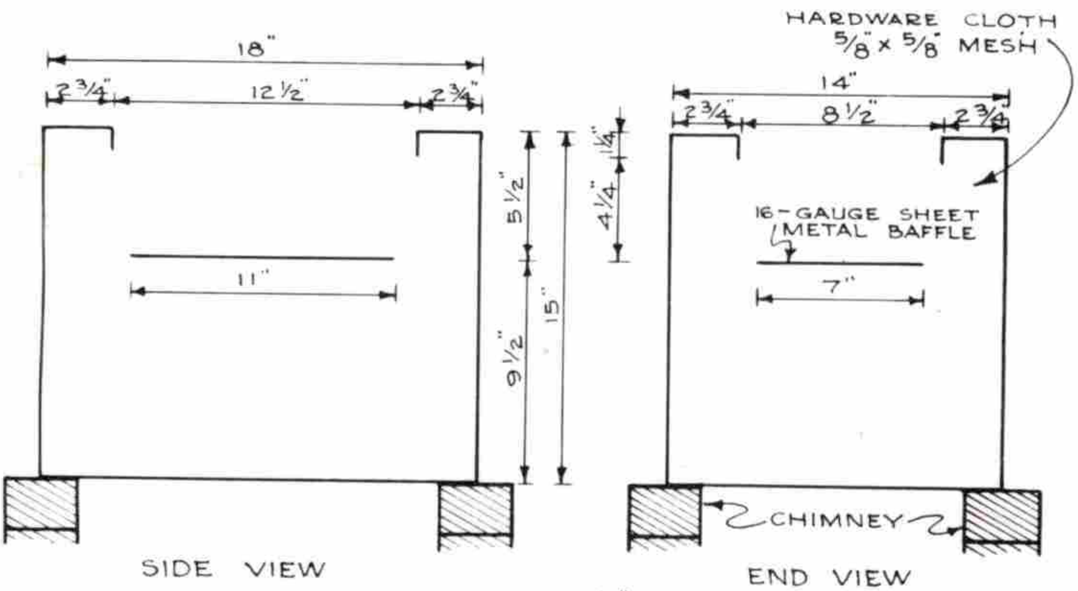
SCALE 1½" = 1'-0"

Fig. 14. SECTIONAL SKETCH OF NO. 2 SPARK ARRESTER



SCALE 1½" = 1'-0

Fig. 16. SECTIONAL SKETCH OF NO. 4 SPARK ARRESTER



SCALE 1½" = 1'-0"

Fig. 15. SECTIONAL SKETCH OF NO.3 SPARK ARRESTER

Number 6

Pioneer Type B Spark Arrester

Manufactured by: James Slocum, Detroit, Michigan

Figure 18

Number 7

National Open Top, Type C Spark Arrester

Manufactured by: National Supply and Service Corp.
Crawfordsville, Indiana

Figure 19

Number 8

New Style Star #2 Spark Arrester

Manufactured by: Star Spark Arrester Company
Oskaloosa, Iowa

Figure 20

Number 9

New Style Star #1 Spark Arrester

Manufactured by: Star Spark Arrester Company
Oskaloosa, Iowa

Figure 21

Number 10

Mullin Spark Arrester

Manufactured by: Mullin Appliance Company, Inc.
Detroit, Michigan

Figure 22

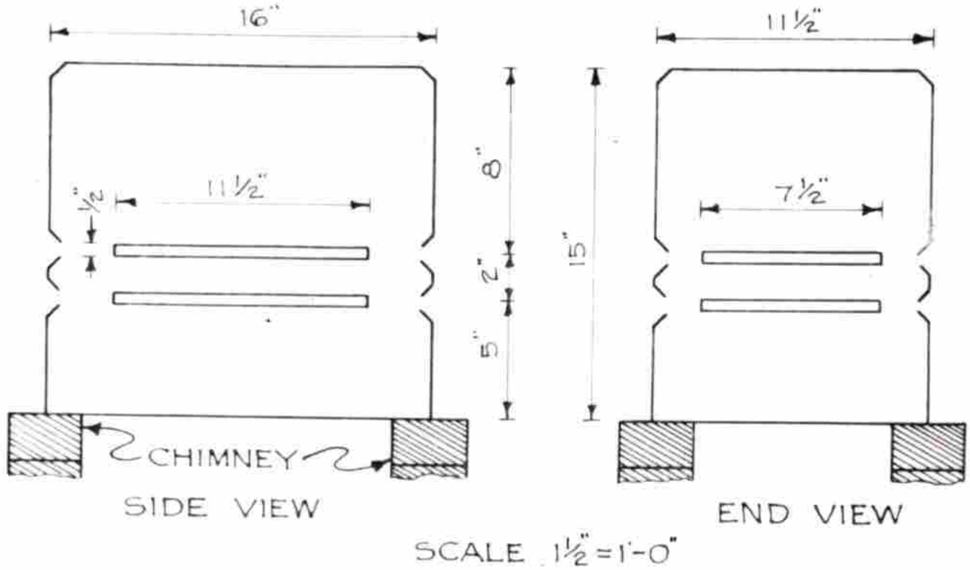


Fig. 17. SECTIONAL SKETCH OF NO. 5 SPARK ARRESTER

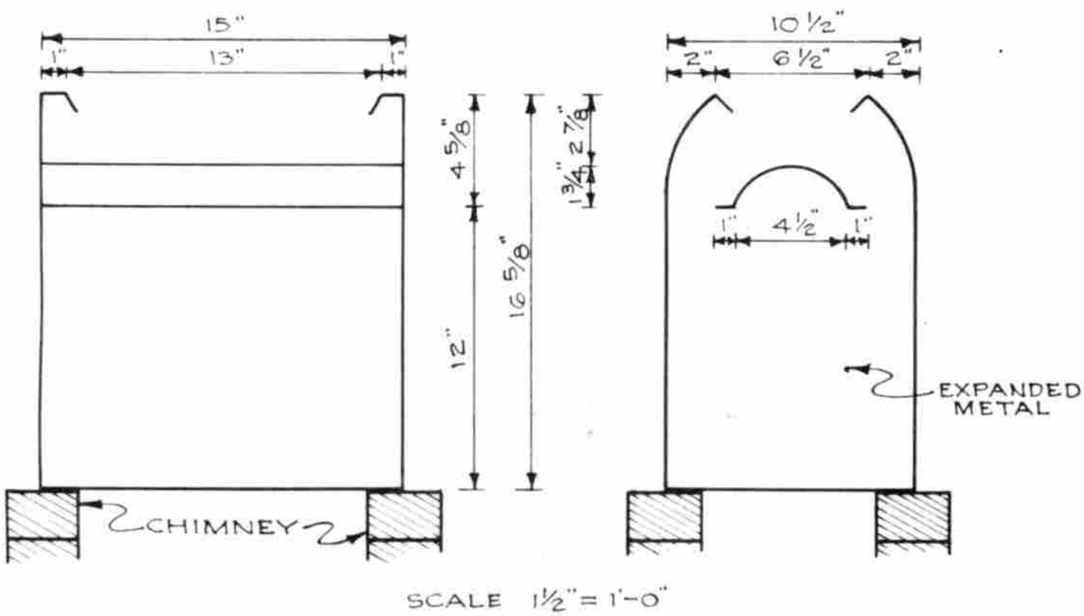


Fig. 18. SECTIONAL SKETCH OF NO. 6 SPARK ARRESTER

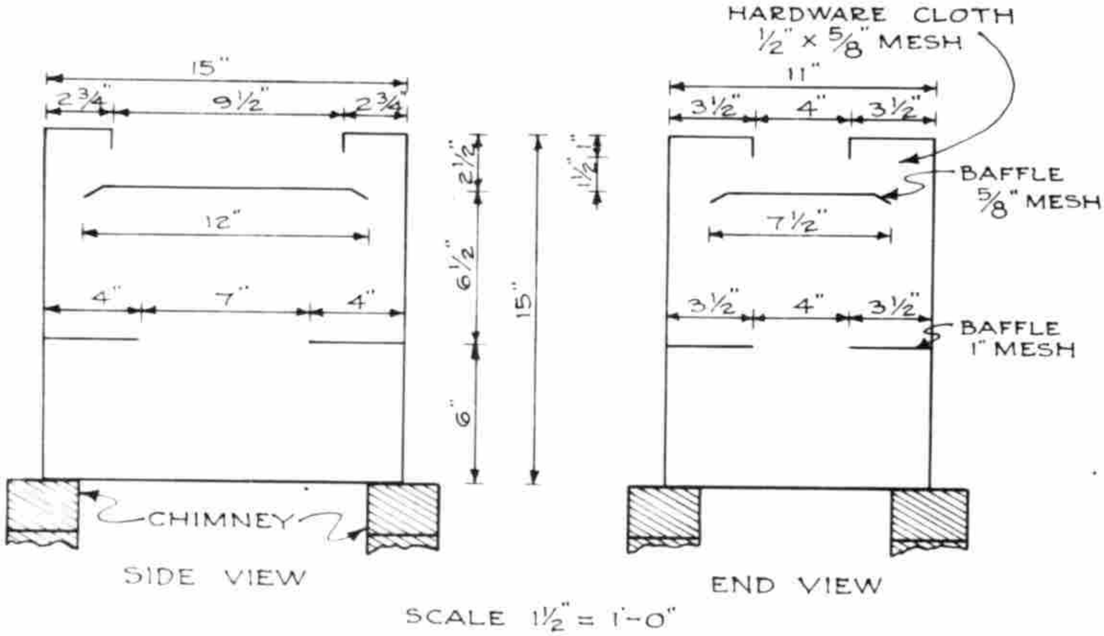


Fig. 19. SECTIONAL SKETCH OF NO.7 SPARK ARRESTER

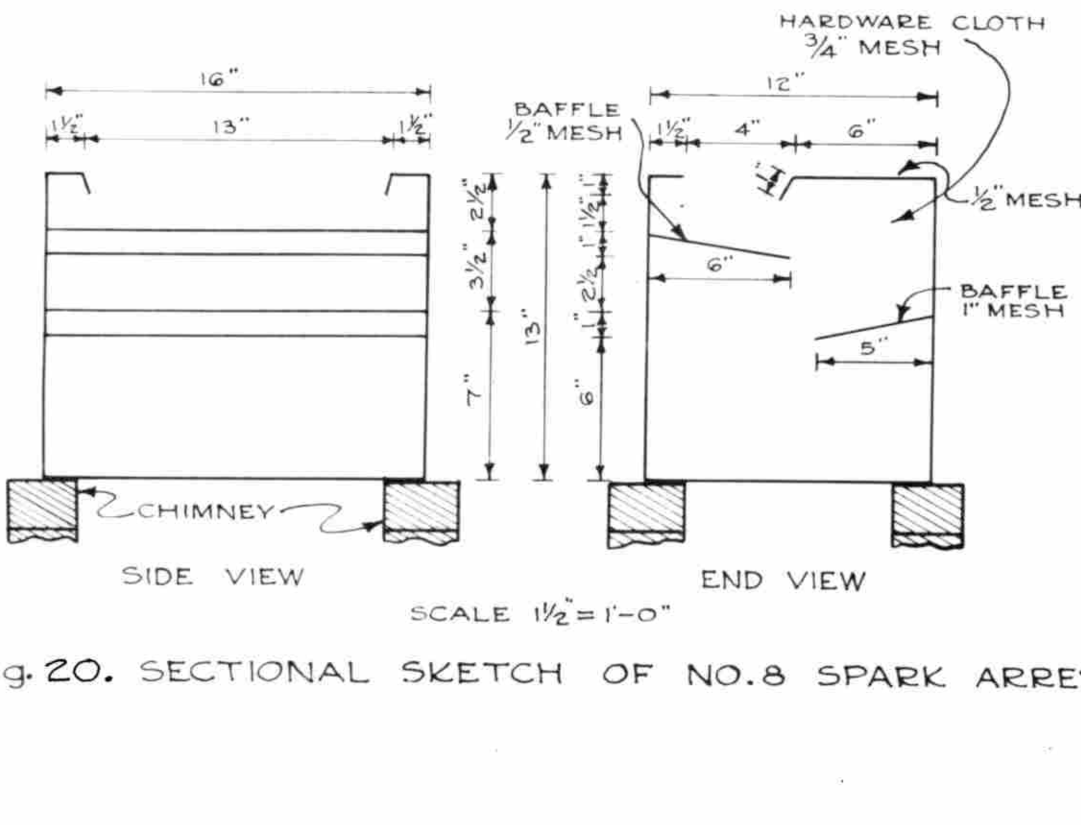


Fig. 20. SECTIONAL SKETCH OF NO.8 SPARK ARRESTER

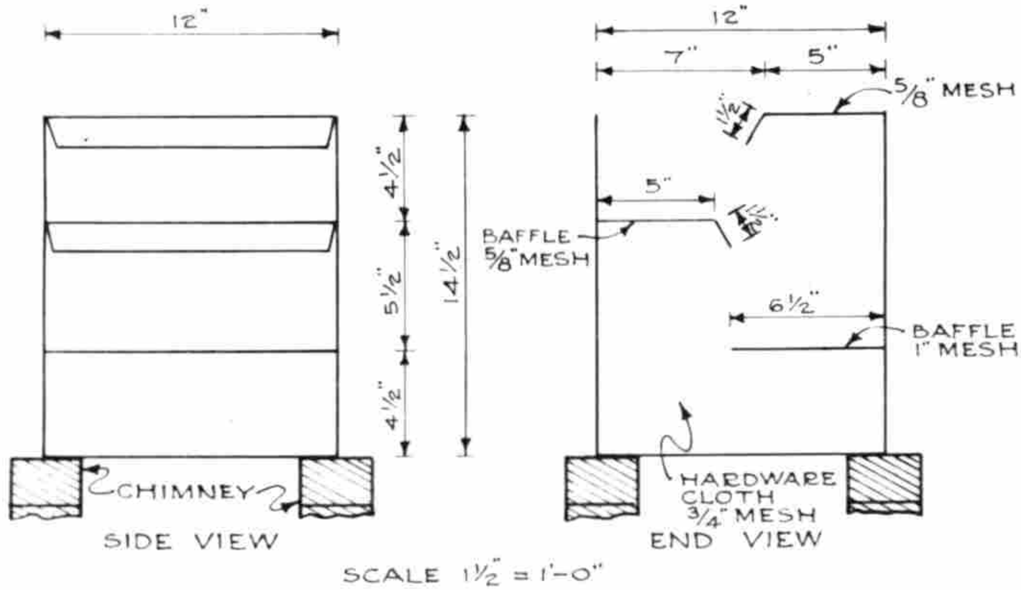


Fig. 21. SECTIONAL SKETCH OF NO. 9 SPARK ARRESTER

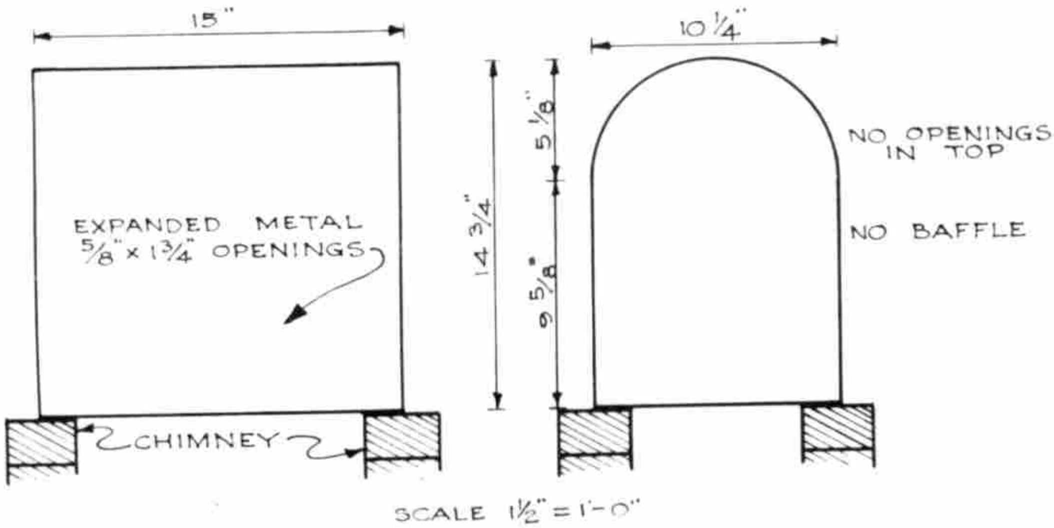


Fig. 22. SECTIONAL SKETCH OF NO. 10 SPARK ARRESTER

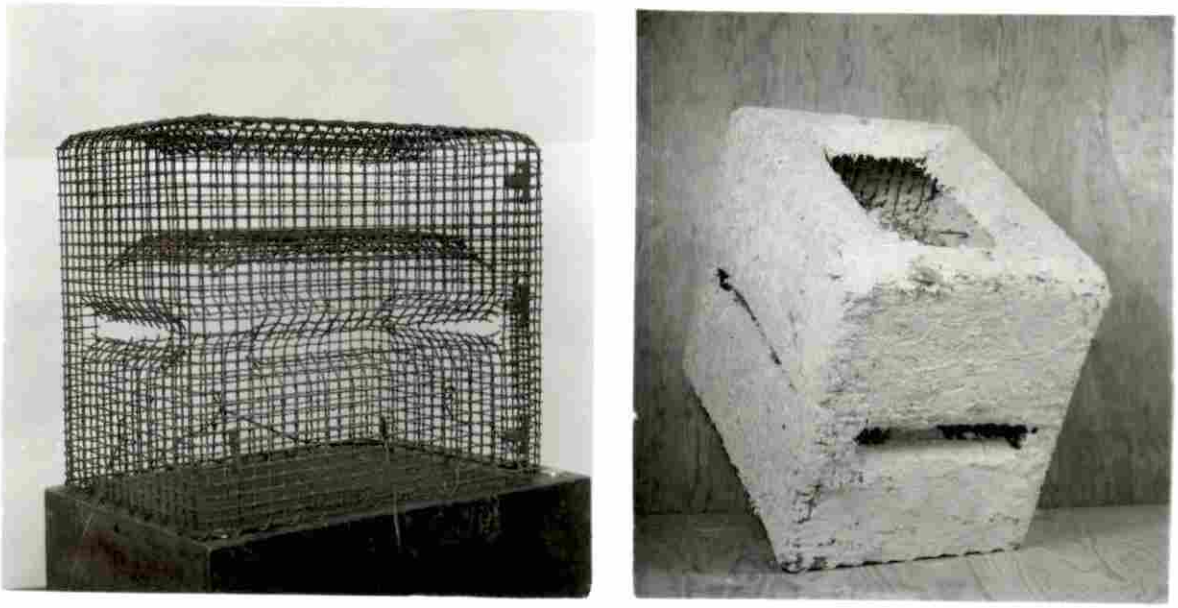
Clogging of spark arresters

After observing actual clogging in the field, an effort was made to approach the nature of this clogging in the laboratory by synthetic means. Utilizing a mixture of casein glue and sawdust, the meshes of each arrester were clogged approximately 40 per cent. Figure 5 shows a typical synthetically clogged arrester.

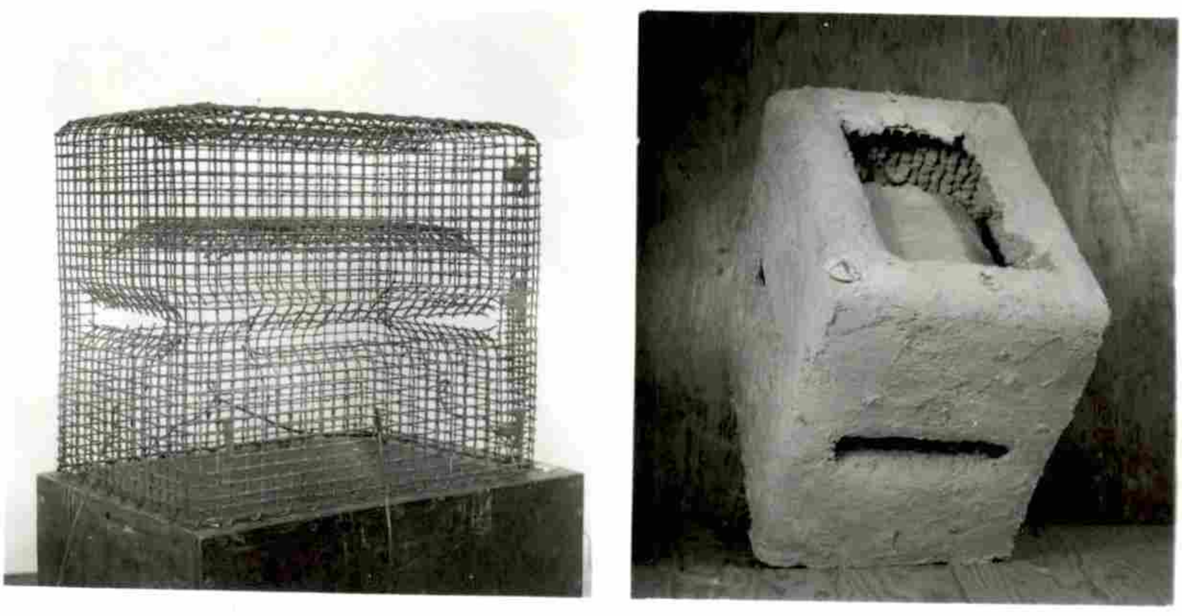
Under the most extreme conditions a spark arrester may become completely clogged except for the calculated free area. Arresters before and after they have been clogged are shown in Figure 23. The arresters were completely clogged by utilizing a mixture of fibered plaster and shredded corn stalk. The degree of fineness of the shredded corn stalk and the size of the opening in the wire mesh used in the construction of the spark arrester determined the proportion of the mixture that could be used. The mixture was applied to the outside of the arrester with a small trowel and rubbed smooth only on the outside. The rough surface on the interior of the arrester would represent, to a certain extent, actual clogging conditions.

Calculation of free area of different spark arresters

All of the spark arresters previously described in this manuscript were made of hardware cloth. The durability of

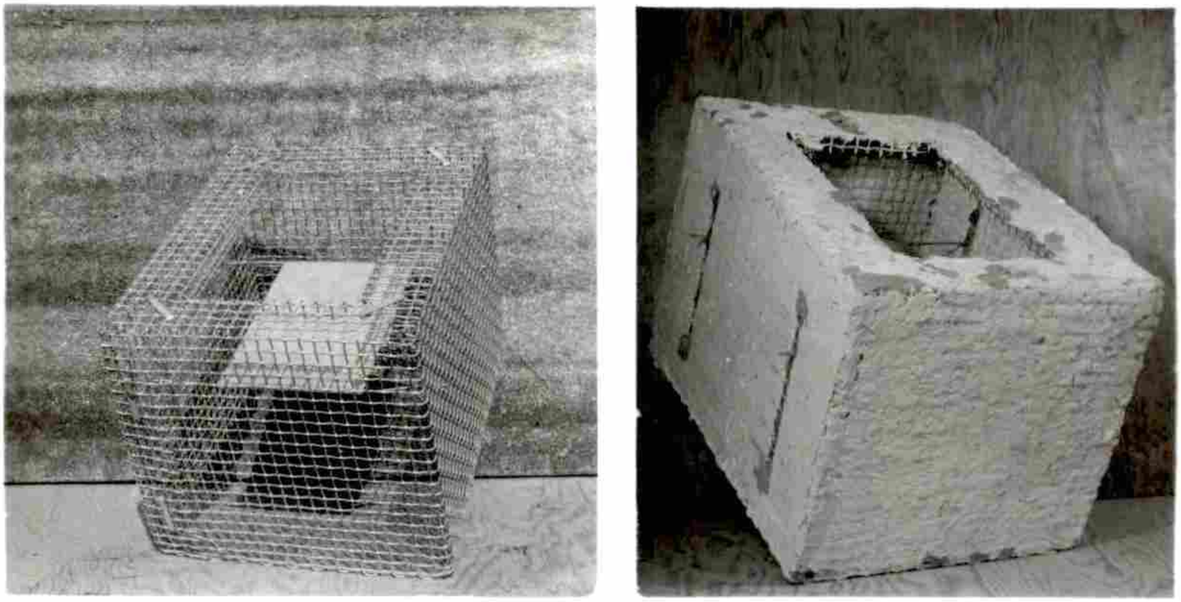


Spark Arrester No. 1



Spark Arrester No. 2

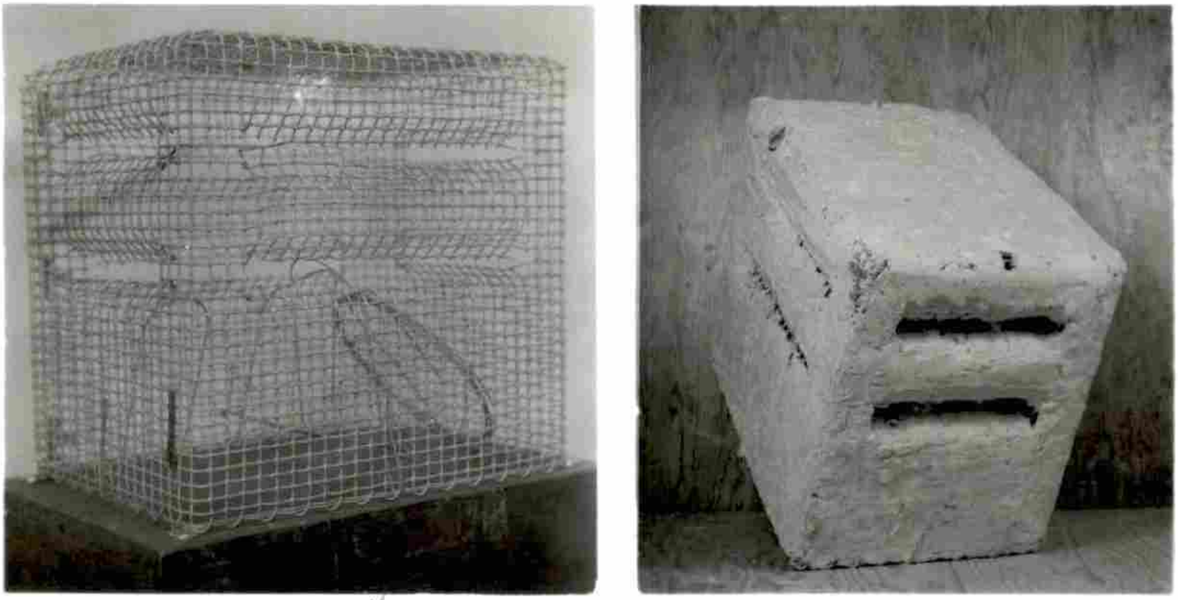
Fig. 23. Spark Arresters Before and After Clogging



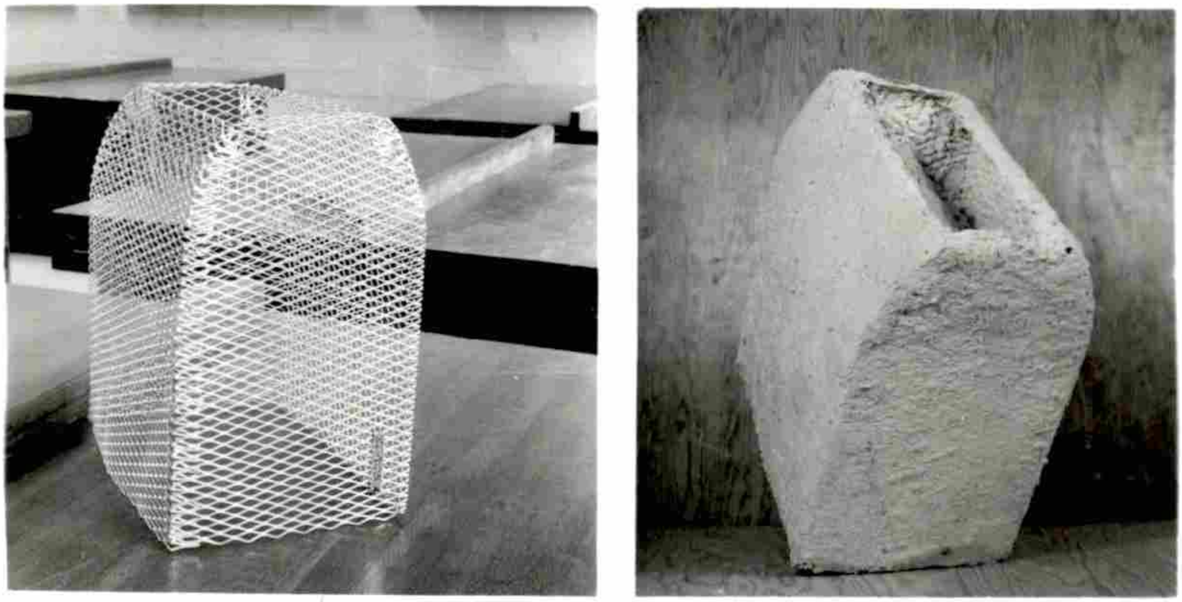
Spark Arrester No. 3

Spark Arrester No. 4

Fig. 23 (cont.)

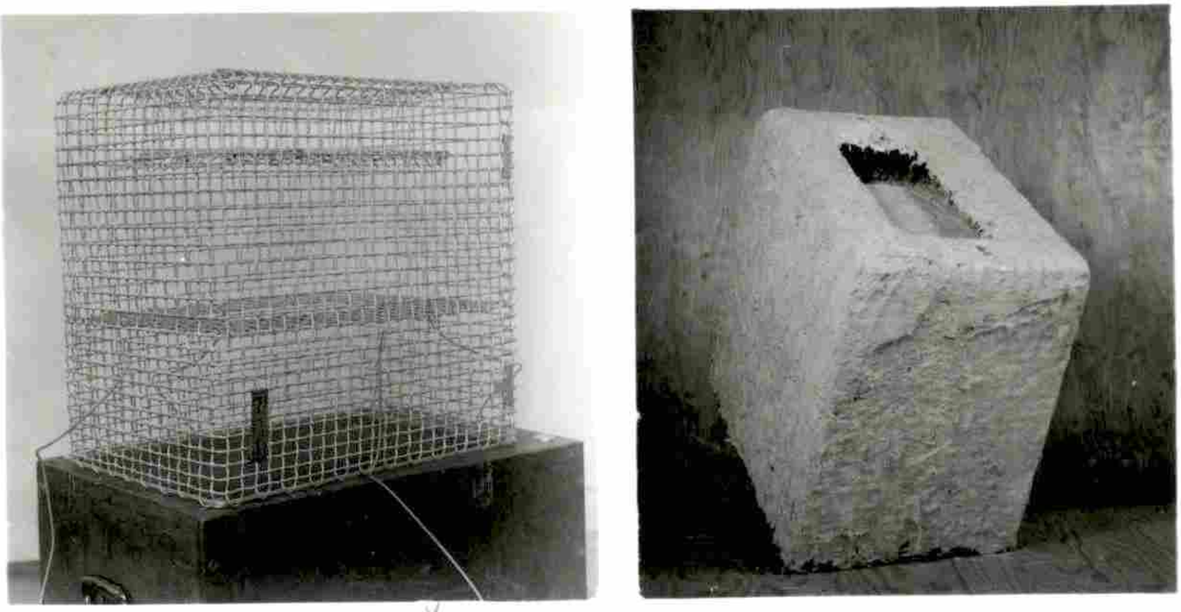


Spark Arrester No. 5

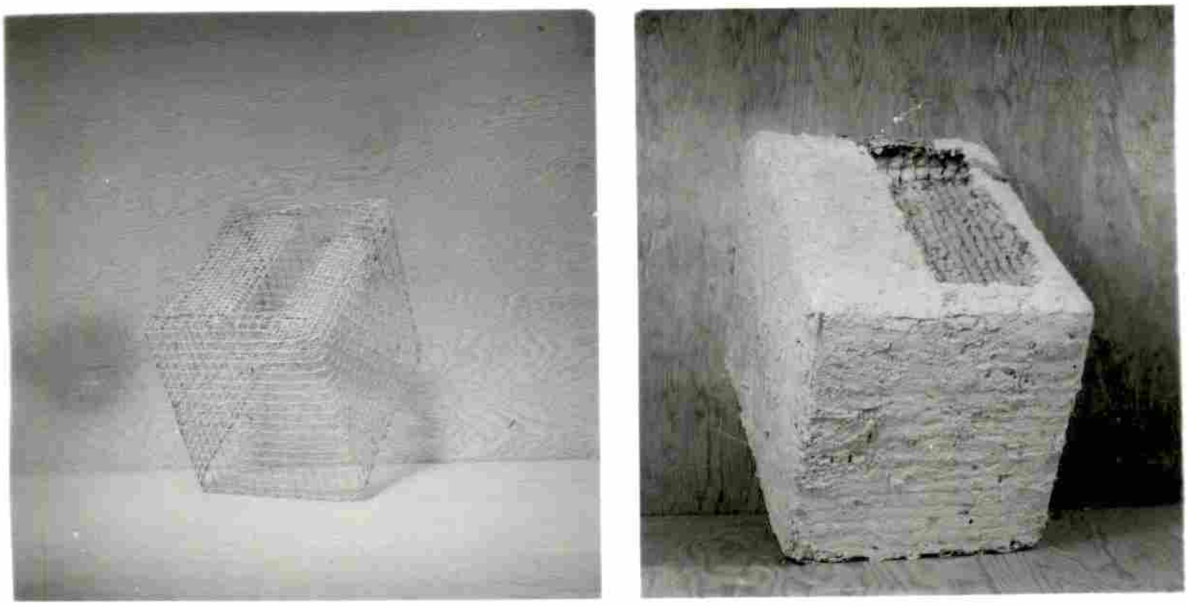


Spark Arrester No. 6

Fig. 23 (cont.)

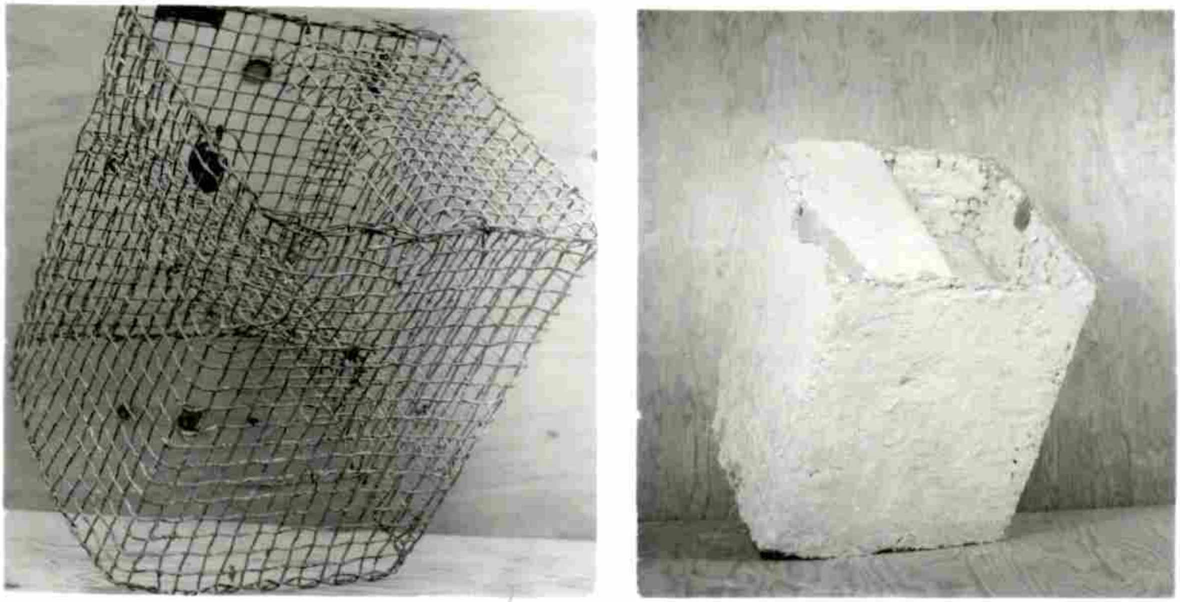


Spark Arrester No. 7.

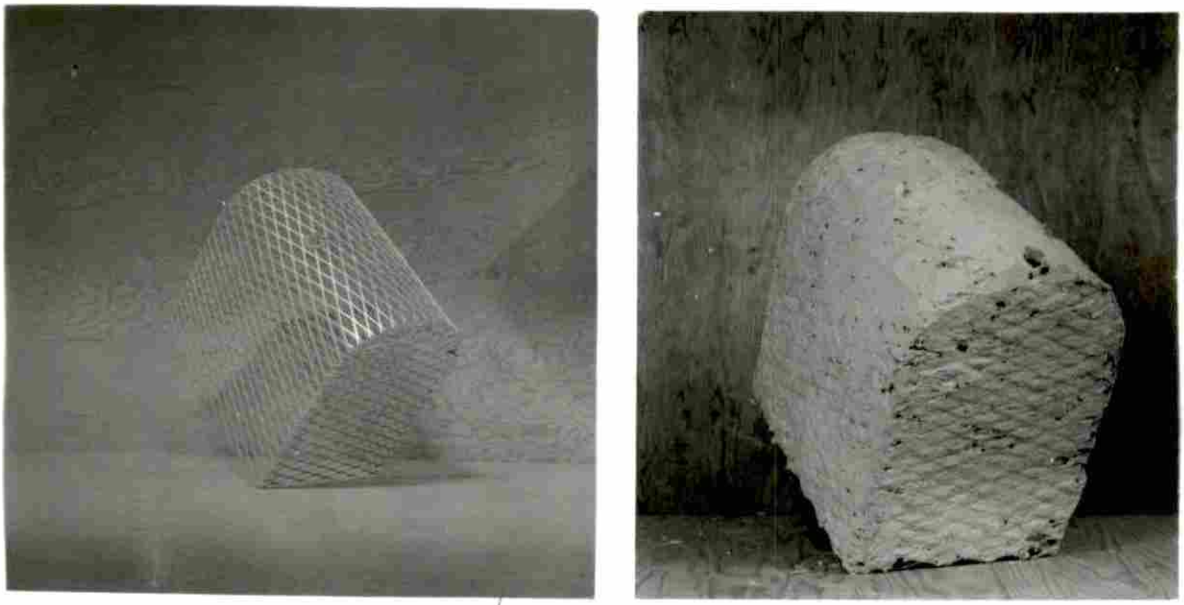


Spark Arrester No. 8.

Fig. 23. (cont.)



Spark Arrester No. 9



Spark Arrester No. 10

Fig. 23 (cont.)

the material, the size of opening between meshes and the size and shape of the arrester would vary very widely. The amount of free area in any arrester refers to openings, in the top or sides of the arrester, which are larger than the size of mesh of which the arrester is constructed.

In the No. 3 arrester the size of the free area is determined by the area of the opening in the top of the arrester, whereas in the case of the No. 5 arrester the area of free opening is determined by rectangular openings cut in the sides of the arrester. The amount of free area in the No. 8 arrester is determined by the size of baffle and the height between the baffles. The amount of free area in each arrester is as follows:

No. 1	-	70 sq. in.	No. 6	-	45 sq. in.
No. 2	-	75 sq. in.	No. 7	-	32 sq. in.
No. 3	-	106 sq. in.	No. 8	-	44 sq. in.
No. 4	-	72 sq. in.	No. 9	-	36 sq. in.
No. 5	-	38 sq. in.	No. 10	-	0 sq. in.

The effect of partially clogged spark arresters upon the flow of air through a small model chimney

Testing procedure. The small model chimney, Figure 4, was used in making this test. The draft gauge was connected to the small openings in the chimney at numbers 1, 2, 3, 4 by means of 1/8-inch rubber tubing. A series of stopcocks arranged as shown in Figure 11 made possible an easy connection to the draft gauge.

The blower was set in operation and the velocity of the air flowing through the chimney was regulated at 945 feet per minute. Pressure readings were taken at each of the openings, using each of the arresters, and the data for the tests are recorded in Table 3. After completing this test the velocity of the air was regulated at 1460 feet per minute and the test repeated. The data for this test are shown in Table 4.

A test to determine the effect of the different types of spark arresters upon the velocity of the air flowing in the chimney was conducted by checking the velocity of the air in the chimney when there was no arrester on the chimney. Then by placing an arrester on the chimney and checking the velocity again, any reduction in the velocity could be readily detected. The velocity was checked in five different places at the top of the chimney by means of the velometer. Readings were taken 2 1/2 inches from each corner and in the center of the chimney. Three different open chimney velocities were used and the data are recorded in Table 5. Only the average velocity reading is shown by the table.

Results of test. The partially clogged spark arresters did not affect the pressure in the chimney or the velocity of the air enough to make the results significant.

The pulsating flow of the air produced by the fan could not be corrected even though a honey-comb baffle was used to straighten out the air currents. The chimney was not of

TABLE 3

The Effect of Partially Clogged Spark Arresters upon the Flow of Air in a Small Model Chimney with Air Velocity in Open Chimney 945 ft./min.

Arrester Number	Pressure in Inches of Water at Different Locations in Chimney			
	1	2	3	4
1	.001	.000	.000	.000
2	.000	.000	.000	.000
3	.002	.000	.000	.000
4	.002	.000	.000	.000
5	.001	.000	.000	.000
6	.000	.000	.000	.000
7	.002	.000	.000	.000
9	.015	.012	.012	.014
10	.005	.000	.000	.000

TABLE 4

The Effect of Partially Clogged Spark Arresters upon the Flow of Air in a Small Model Chimney with Air Velocity in Open Chimney 1460 ft./min.

Arrester Number	Pressure in Inches of Water at Different Locations in Chimney			
	1	2	3	4
1	.006	.003	.002	.001
2	.000	.000	.000	.000
3	.002	.002	.002	.001
4	.000	.000	.000	.000
5	.000	.000	-.008	-.001
6	.001	.000	.000	.000
7	.006	.003	.002	.002
9	.025	.024	.024	.021
10	.000	.000	.000	.000

TABLE 5

The Effect of Partially Clogged Spark Arresters upon the Velocity of Air Flowing through a Small Model Chimney

Arrester Number	Velocity of Air in Chimney ft./min.			% of 660 F.P.M.	% of 1015 F.P.M.	% of 1470 F.P.M.
1	645	995	1,420	97.7	98.0	96.5
2	660	1,005	1,435	100.0	99.0	97.5
3	645	995	1,435	97.7	98.0	97.5
4	650	1,000	1,440	98.5	98.5	98.0
5	660	995	1,470	100.0	98.0	100.0
7	645	1,005	1,450	97.7	99.0	98.6
9	620	915	1,370	94.0	90.2	93.2
10	655	1,005	1,440	99.3	99.0	98.0
Open Chimney	660	1,015	1,470			

uniform cross section and only four feet high, so it was decided to construct a model chimney which was much higher and of uniform cross section above the baffle.

The effect of partially clogged spark arresters upon the flow of air in a large model chimney

The fact that partially clogged spark arresters did not have a significant effect upon the flow of air in a small model chimney made it necessary to continue the investigation and determine the effect of partially clogged arresters upon the flow of air in a large model chimney. Figures 7 and 9 show the model chimney which was constructed and used in this test. The blower and equipment used in making this test were the same as those previously described for the test using a small chimney.

Testing procedure. The testing procedure was essentially the same as that previously described for the small model chimney except for the fact that in the case of the large model chimney there were six openings in the height of the chimney from which pressure readings could be taken.

The blower was set in operation and the velocity of the air flowing through the chimney was regulated at 580 feet per minute. Before placing an arrester on the chimney the pressure at each of the six openings was recorded. An arrester was then placed on top of the chimney and the velocity of the air flowing and the pressure at each of the openings were checked and recorded. All of the arresters were checked in this manner, using an open chimney air velocity of 580 feet per minute. This same test was repeated using open chimney air velocities of 1050 and 1300 feet per minute. All of the data were recorded in Tables 6, 7, and 8.

The velocity readings recorded in the tables were obtained by taking the mean average of three sets of full readings. Only the mean average velocity is shown in the tables. All of the velocity readings were taken at the top of the chimney by means of the velometer equipped with the 2425-18 jet.

The pressure readings recorded in the tables were obtained by taking the average of three sets of readings at each station. Only the average reading for each station is shown in the tables. Going from bottom to top of chimney the openings are numbered from 0 to 6. The first opening from the bottom of the chimney was not used in the test.

Results of test. The arresters did not have a significant effect upon the pressure when the air velocity was 580 feet per minute. However, the velocity was reduced as much as 8.6 per cent in the case of some of the arresters. Figure 24. It is interesting to note that as the velocity of the air increased, the amount of pressure produced in the chimney increased. All of the arresters produced practically the same results for the velocities used except Nos. 8 and 9. In

TABLE 6

The Effect of Partially Clogged Spark Arresters upon the Flow of Air in a Large Model Chimney with Air Velocity in Open Chimney 580 ft./min.

Arrester Number	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Velocity of Air with Arrester: ft./min.	Velocity of Air % of 580 ft./min.
1 41	.001	.001	.000	.000	.000	.000	560	96.5
2 42	.001	.000	.000	.000	.000	.000	550	94.8
3 38	.001	.001	.000	.000	.000	.000	540	93.1
4 37	.001	.000	.000	.000	.000	.000	550	94.8
5 22	.001	.000	.000	.000	.000	.000	560	96.5
6 31	.001	.000	.000	.000	.000	.000	570	98.3
7 32	.001	.001	.000	.000	.000	.000	570	98.3
8 34	.003	.002	.002	.001	.002	.001	540	93.1
9 33	.006	.005	.005	.004	.004	.003	530	91.4
10 11	.001	.001	.000	.000	.000	.000	560	96.5
No Arrester	.000	.000	.000	.000	.000	.000		

TABLE 7

The Effect of Partially Clogged Spark Arresters upon the Flow of Air in a Large Model Chimney with Air Velocity in Open Chimney 1050 ft./min.

Arrester Number	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Velocity of Air with Arrester ft./min.	Velocity of Air % of 1050 ft./min.
1	.013	.010	.008	.005	.005	.004	1040	99.0
2	.013	.010	.006	.004	.005	.003	1050	100.0
3	.013	.010	.008	.005	.006	.004	1030	98.0
4	.016	.013	.010	.005	.006	.004	1040	99.0
5	.014	.010	.008	.004	.005	.003	1020	98.1
6	.011	.010	.006	.004	.005	.004	1040	99.0
7	.013	.010	.006	.004	.005	.003	1050	100.0
8	.021	.019	.016	.013	.014	.012	1000	95.2
9	.021	.021	.020	.017	.019	.016	1020	98.1
10	.012	.010	.006	.004	.005	.004	1050	100.0
No Arrester	.012	.009	.007	.004	.004	.001		

TABLE 8

The Effect of Partially Clogged Spark Arresters upon the Flow of Air in a Large Model Chimney with Air Velocity in Open Chimney 1300 ft./min.

Arrester Number	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Velocity of Air: With Arrester ft./min.	% of 1300 ft./min.
1	.020	.015	.010	.005	.008	.005	1300	100.0
2	.019	.014	.010	.004	.007	.005	1300	100.0
3	.020	.015	.012	.006	.010	.006	1300	100.0
4	.020	.015	.011	.005	.009	.005	1300	100.0
5	.017	.014	.009	.003	.005	.004	1300	100.0
6	.020	.015	.010	.005	.006	.005	1300	100.0
7	.019	.014	.010	.005	.008	.005	1300	100.0
8	.024	.022	.021	.015	.019	.015	1210	93.1
9	.026	.025	.025	.023	.024	.024	1200	92.2
10	.017	.012	.009	.004	.006	.004	1300	100.0
No Arrester	.016	.014	.010	.003	.006	.003		

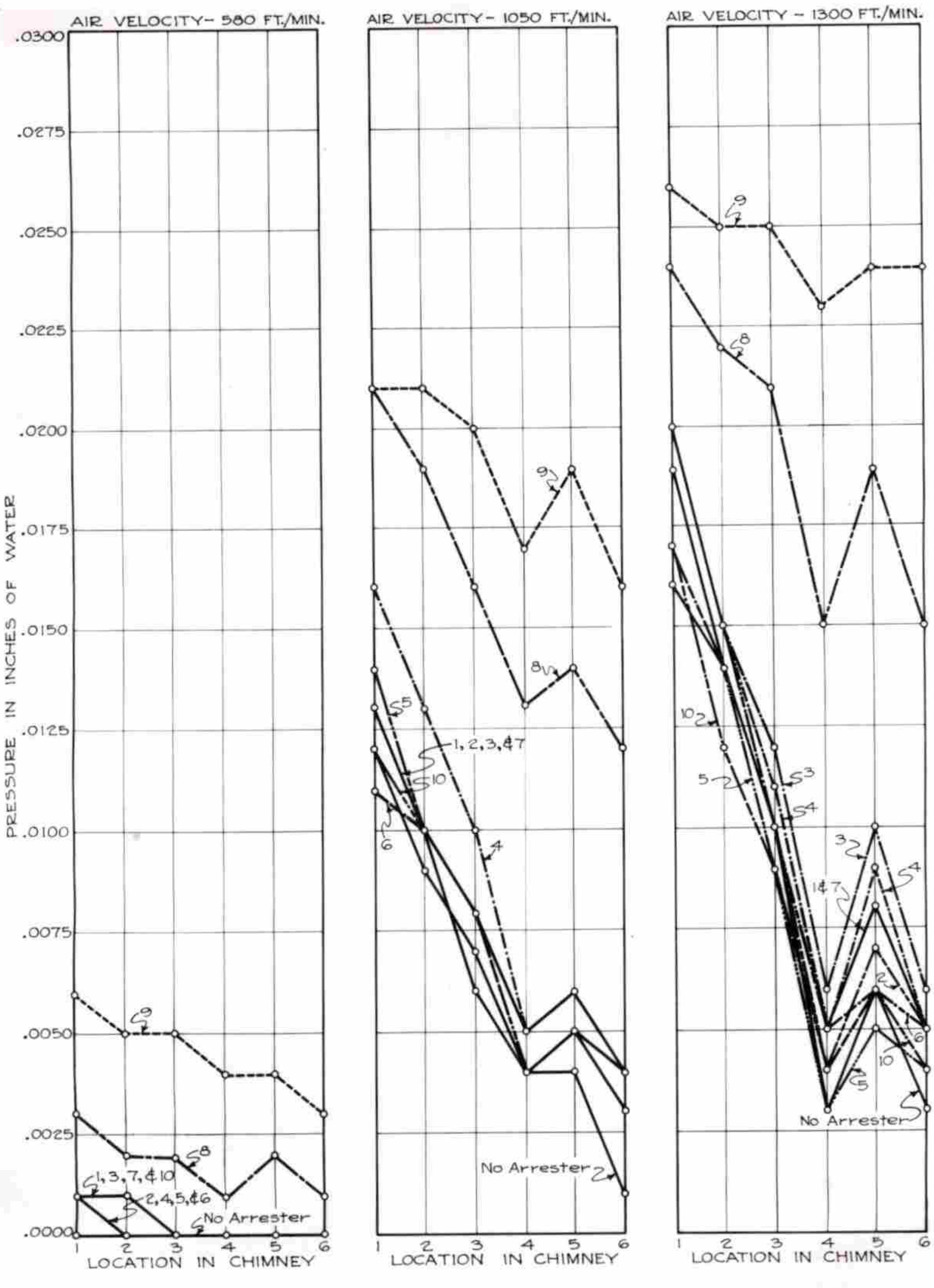


Fig. 24. THE EFFECT OF PARTIALLY CLOGGED SPARK ARRESTERS UPON THE PRESSURE OF AIR FLOWING THROUGH A LARGE MODEL CHIMNEY

every case arresters Nos. 8 and 9 produced the greatest amount of pressure in the chimney.

Only 40 per cent of the arresters were clogged, and for this reason further tests should be made to determine the effect of completely clogged arresters upon the flow of air in model chimneys.

<u>The effect of clogged spark arresters upon the flow of air in a large model chimney</u>

The spark arresters which have been used in the tests previously described were only 40 per cent clogged. A study of spark arresters which have been in use for some time indicate that under certain conditions it is possible for the arresters to become completely clogged except for at least a part of the free area.

All of the arresters used in making this series of tests were completely clogged except for the calculated free area.

<u>Testing procedure</u>. The method of procedure in making the tests is essentially the same as that previously described for the test using partially clogged arresters, except that in this case open chimney velocities of 425, 570, 805, 1030, and 1430 feet per minute were used. The data for each velocity are shown in Tables 9, 10, 11, 12, and 13. The air velocity with each arrester and the per cent of open chimney velocity are also shown in the tables. The data are graphically

TABLE 9

The Effect of Clogged Spark Arresters upon
the Flow of Air in a Large Model Chimney with
Air Velocity in Open Chimney 425 ft./min.

Arrester	Pressure in Inches of Water at Different Locations in Chimney						Air Velocity in Chimney ft./min.	
Number	1	2	3	4	5	6	With Arrester	% of 425
1	.020	.020	.020	.020	.020	.020	325	76.5
2	.027	.027	.027	.027	.027	.027	320	75.3
3	.029	.029	.029	.029	.030	.030	350	82.4
4	.030	.030	.030	.030	.030	.030	300	70.6
5	.040	.040	.040	.040	.040	.040	360	84.7
6	.060	.060	.060	.060	.060	.060	240	56.5
7	.075	.075	.075	.075	.075	.075	195	45.8
8	.086	.086	.086	.086	.086	.086	180	42.3
9	.100	.100	.100	.100	.100	.100	160	37.6
10	.140	.140	.140	.140	.140	.141	230	54.1
No Arrester	.005	.005	.005	.005	.005	.005		

TABLE 10

The Effect of Clogged Spark Arresters upon the Flow of Air in a Large Model Chimney with Air Velocity in Open Chimney 570 ft./min.

Arrester	Pressure in Inches of Water at Different Locations in Chimney						Air Velocity in Chimney ft./min.	
Number	1	2	3	4	5	6	With Arrester	% of 570
1	.041	.041	.041	.041	.041	.041	530	93.0
2	.040	.040	.040	.040	.040	.040	500	87.7
3	.045	.045	.045	.045	.045	.045	490	86.0
4	.049	.048	.047	.046	.045	.045	490	86.0
5	.060	.060	.060	.060	.060	.060	470	82.5
6	.082	.082	.082	.082	.082	.082	380	66.6
7	.115	.115	.115	.115	.115	.115	260	45.6
8	.124	.124	.124	.124	.124	.124	250	43.8
9	.120	.120	.120	.120	.120	.120	240	41.1
10	.169	.168	.166	.166	.166	.166	30	5.3
No Arrester	.009	.009	.009	.008	.007	.005		

TABLE 11

The Effect of Clogged Spark Arresters upon the Flow of Air in a Large Model Chimney with Air Velocity in Open Chimney 805 ft./min.

Arrester	Pressure in Inches of Water at Different Locations in Chimney						Air Velocity in Chimney ft./min.	
Number	1	2	3	4	5	6	With Arrester	% of 805
1	.060	.060	.060	.060	.060	.060	674	83.6
2	.060	.060	.060	.060	.060	.060	640	79.5
3	.070	.070	.070	.070	.070	.070	625	77.7
4	.070	.070	.070	.070	.070	.070	640	79.5
5	.090	.090	.090	.090	.090	.090	595	74.0
6	.120	.120	.120	.120	.120	.120	538	66.8
7	.140	.140	.140	.140	.140	.140	360	44.7
8	.160	.160	.160	.160	.160	.160	335	41.6
9	.160	.160	.160	.160	.160	.160	295	36.6
10	.183	.180	.180	.180	.183	.183	100	12.8
No Arrester	.005	.004	.004	.003	.003	.002		

TABLE 12

The Effect of Clogged Spark Arresters upon the Flow of Air in a Large Model Chimney with Air Velocity in Open Chimney 1030 ft./min.

Arrester	Pressure in Inches of Water at Different Locations in Chimney						Air Velocity in Chimney ft./min.	
Number	1	2	3	4	5	6	With Arrester	% of 1030
1	.090	.090	.090	.090	.090	.090	810	78.6
2	.105	.105	.105	.105	.105	.105	800	77.7
3	.110	.110	.110	.110	.110	.110	760	73.9
4	.110	.110	.110	.110	.110	.110	720	69.9
5	.125	.125	.125	.125	.125	.125	660	64.0
6	.163	.163	.163	.162	.162	.162	510	49.5
7	.180	.180	.180	.180	.180	.180	380	36.8
8	.190	.190	.190	.190	.190	.190	365	35.4
9	.190	.190	.190	.190	.190	.190	360	35.0
10	.210	.210	.210	.210	.210	.210	50	4.9
No Arrester	.011	.011	.011	.011	.011	.011		

TABLE 13

The Effect of Clogged Spark Arresters upon the Flow of Air in a Large Model Chimney with Air Velocity in Open Chimney 1430 ft./min.

Arrester	Pressure in Inches of Water at Different Locations in Chimney						Air Velocity in Chimney ft./min.	
Number	1	2	3	4	5	6	With Arrester	% of 1430
1	.140	.140	.140	.140	.140	.140	1010	70.7
2	.160	.160	.160	.160	.160	.160	990	69.2
3	.170	.170	.170	.170	.170	.170	970	67.8
4	.170	.170	.170	.170	.170	.170	915	64.0
5	.180	.180	.180	.180	.180	.180	860	60.2
6	.220	.220	.220	.220	.220	.220	595	41.6
7	.220	.220	.220	.220	.220	.220	500	35.0
8	.220	.220	.220	.220	.220	.220	450	31.4
9	.220	.220	.220	.220	.220	.220	375	26.2
10	.230	.230	.230	.220	.220	.220	100	7.0
No Arrester	.020	.020	.010	.008	.005	.005		

represented by Figure 25.

The effect of each spark arrester upon the velocity of the air flowing through the chimney for each open chimney velocity used is shown in Table 14 and graphically represented in Figure 26 for four of the velocities.

Results of test. The clogged spark arrester affected the pressure and velocity of the air flowing in the chimney. It is interesting to note that the static pressure in the chimney was constant throughout the height of the chimney when the clogged arresters were used. This occurrence was due to the fact that the blower would build up a constant pressure, the magnitude of which depended upon the resistance offered by the arrester to flow of air.

The velocity of the air flowing through the arresters was reduced to as low as 4.9 per cent of the original velocity. Arresters Nos. 1, 2, 3, and 4 gave the best results throughout the test.

The effect of different size and location of baffle in a No. 3 arrester upon the flow of air in a large model chimney

The No. 3 arrester which has been previously described in this manuscript was selected and used for conducting the test. The arrester, Figure 27, was constructed of 5/8-inch wire mesh and equipped with a solid sheet metal baffle.

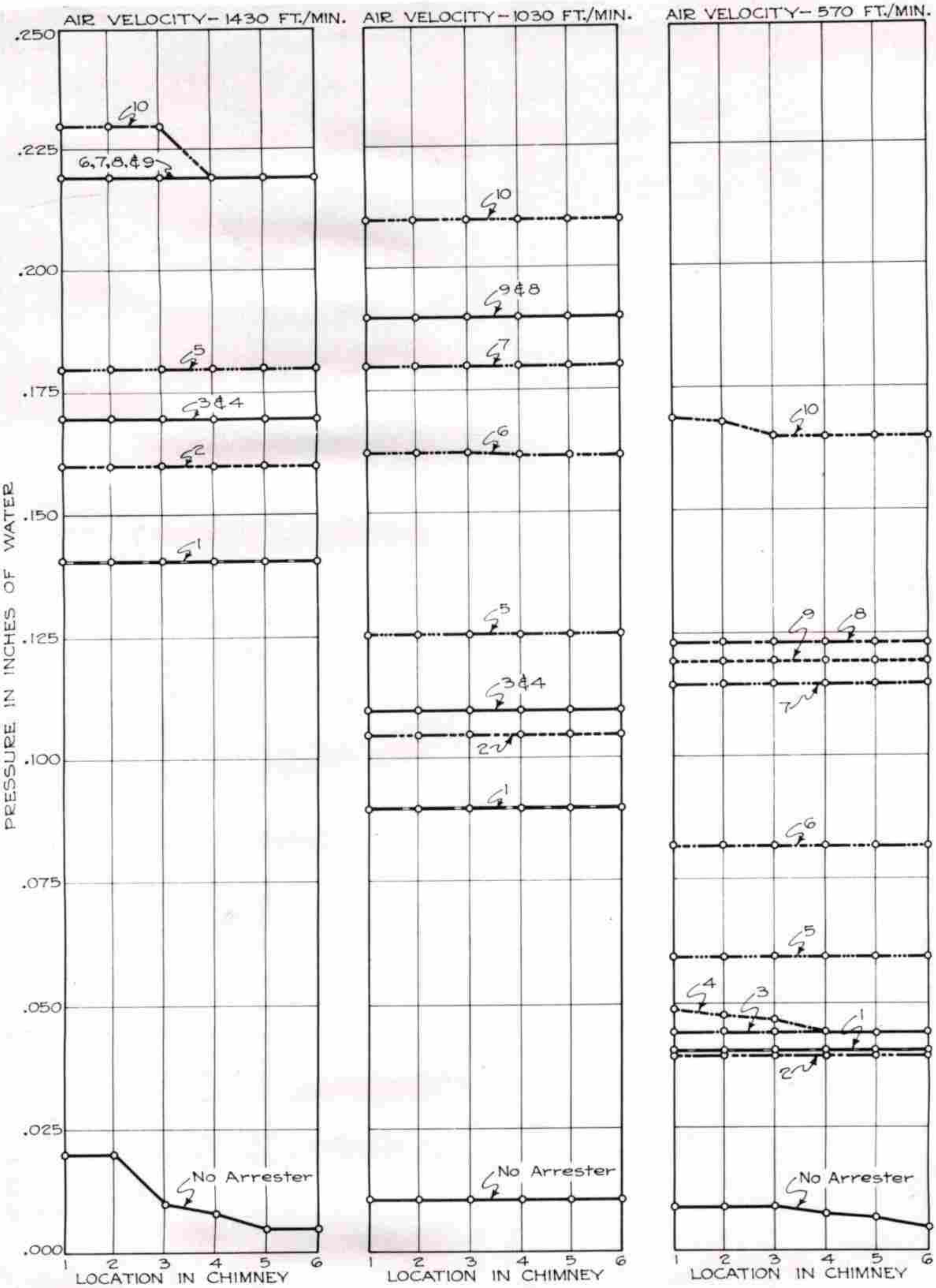


Fig. 25. THE EFFECT OF COMPLETELY CLOGGED SPARK ARRESTERS UPON THE PRESSURE OF AIR FLOWING THROUGH A LARGE MODEL CHIMNEY

TABLE 14

Effect of Clogged Spark Arresters upon the

Velocity of Air Flowing through a Large Model Chimney

Arrester Number	Velocity of Air in Chimney ft. per min.					Per cent of Open Chimney Velocity ft. per min.				
1	325	530	674	810	1010	76.5	93.0	83.6	78.6	70.7
2	320	500	640	800	990	75.4	87.7	79.5	77.7	69.2
3	330	490	625	760	970	77.6	86.0	77.7	73.9	67.8
4	300	490	640	720	915	70.6	86.0	79.5	69.9	64.0
5	360	470	595	660	860	84.7	82.5	74.0	64.0	60.2
6	240	380	538	510	595	56.5	66.6	66.8	49.5	41.6
7	195	260	360	380	500	45.9	45.6	44.7	36.8	35.0
8	180	250	335	365	450	42.4	43.8	41.6	35.4	31.4
9	160	240	295	360	375	37.6	41.1	36.6	35.0	26.2
10	230	30	100	50	100	54.1	5.3	12.8	4.9	7.0
No Arrester	425	570	805	1030	1430	425.0	570.0	805.0	1030.0	1430.0

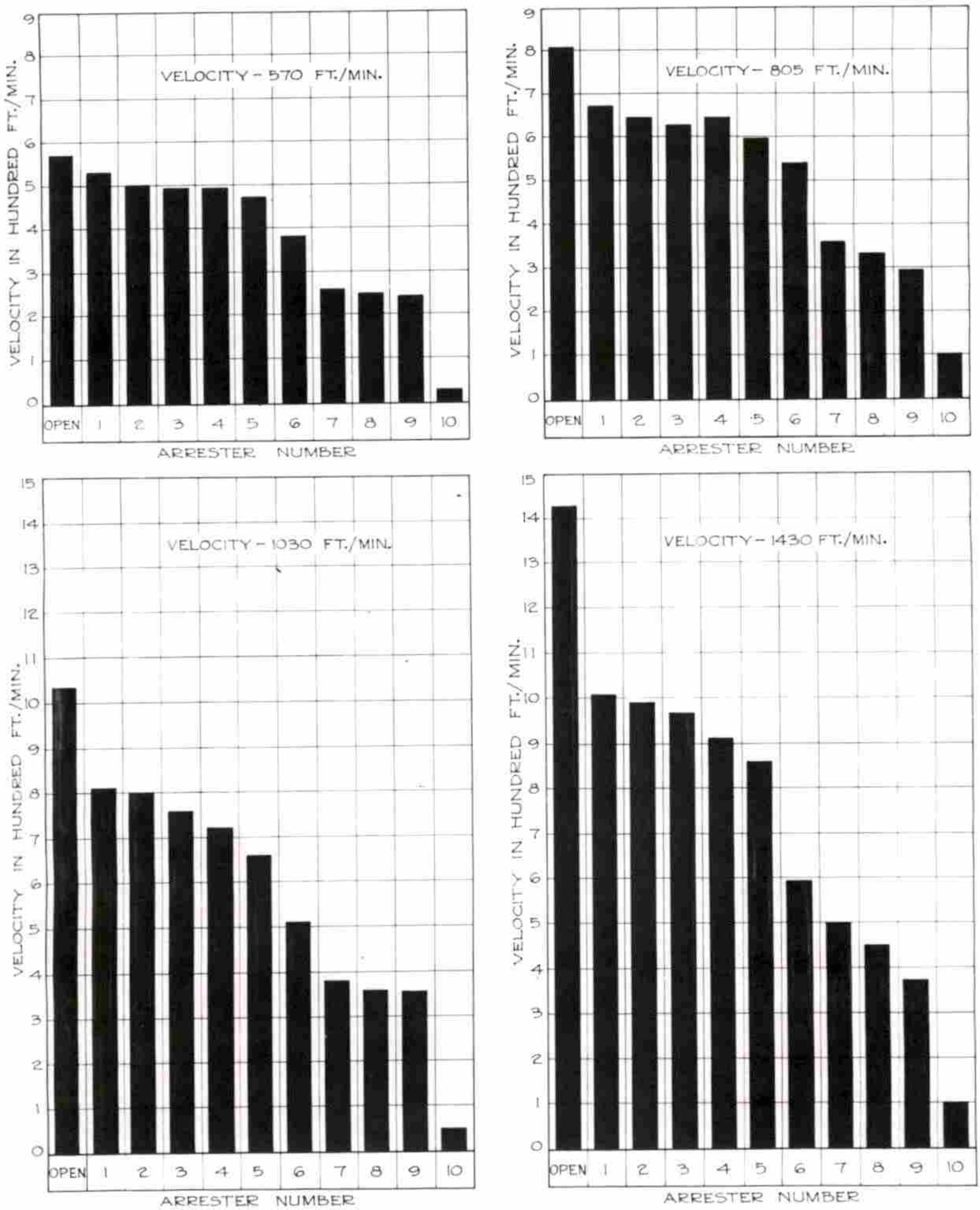


Fig. 26. THE EFFECT OF CLOGGED SPARK ARRESTERS UPON FOUR DIFFERENT VELOCITIES OF AIR FLOWING THROUGH A LARGE MODEL CHIMNEY

A test (5) which was conducted to determine the efficiency of the No. 3 arrester, when equipped with different size and location of baffle, indicates that there is a very definite location for each size of baffle used. After making a study of the report (5) it was decided to determine the best location of each size baffle with reference to the resistance offered to the flow of a column of air.

Set-up for making test. The set-up for testing the arrester was practically the same as that previously described and used to determine the effect of clogged arrester upon the flow of air in a large model chimney except for the fact that in this case only one arrester was used and the variables were the size of the baffle and the location of the baffle above the top of the chimney.

The different sizes of flat metal baffles selected for use in the test are as follows: 7 1/2 x 11 1/2, 7 x 11, 5 1/2 x 9 1/2, and 4 1/2 x 8 1/2 inches. Figure 28 shows the flat baffles arranged in the order in which they were tested. It was decided to test the arresters at different air velocities and for this reason velocities of 530, 853, 1114, and 1510 feet per minute were selected. The reason for selecting these velocities was due to the fact that velocities below 500 feet per minute could not be read very easily on the high range of the velometer and the blower would not furnish an air flow of greater velocity than 1510 feet per minute.

Fig. 27. No. 3 Arrester Used in Test

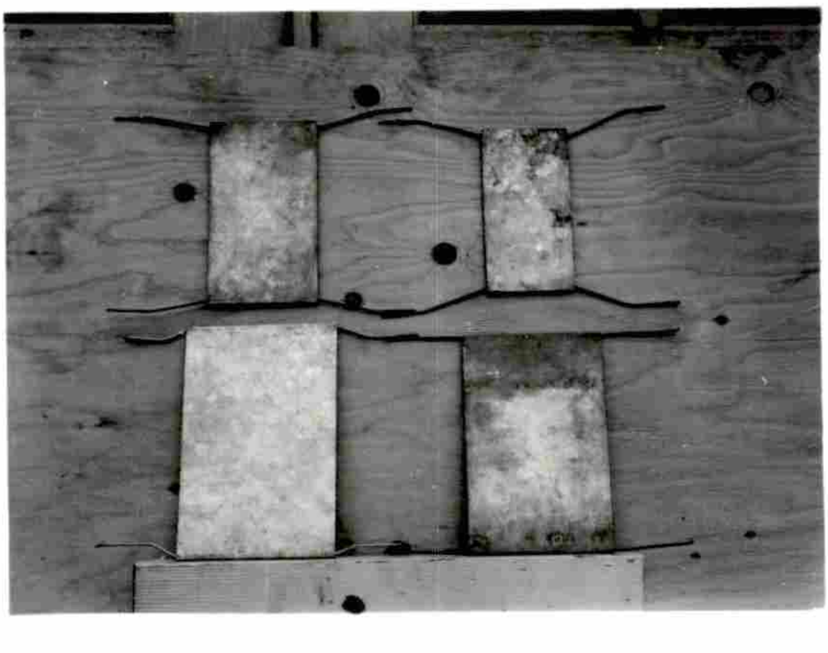


Fig. 28. Sheet Metal Baffles Used in Test

The arrester was completely clogged except for the free area in the top and two narrow openings in each side of the arrester. The openings in the side made it possible to place the baffle at different heights without difficulty. After starting the test, however, it was observed that a great deal of air escaped through the small openings in the side of the arrester and around the bottom of the arrester where it rested on the top of the chimney. The openings in the sides of the arrester were closed by threading friction tape through the openings in the wire mesh. After placing the tape over and through the openings in the wire mesh it was necessary to punch holes in the tape with a sharp pointed knife so that the baffle height could be changed very easily. The air escaping between the bottom of the arrester and the top of the chimney was stopped by placing insulating tape on top of the chimney and placing the arrester on the insulating tape.

Testing procedure. The blower was started and the air velocity in the chimney without the arrester was regulated at 530 feet per minute. The No. 3 arrester, with a 7 1/2 x 11 1/2 inch baffle located 3 1/4 inches from the bottom of the arrester, was placed on the chimney. While the baffle was located in this position the static pressure at different heights in the chimney was checked and recorded. The velocity of the air was also checked and recorded. Three pressure readings were taken at each location in the chimney and averaged to get the velocity recorded in Table 15. The velocity of the air was checked by taking readings in each corner and in the center of the chimney; the five readings were averaged to get the velocity. Three such readings were taken and averaged to get the mean velocity reading which is recorded in the tables. After recording the velocity and static pressure with the 7 1/2 x 11 1/2-inch baffle located 3 1/4 inches from the bottom of the arrester the baffle was located 4 1/2", 5 3/4", 7", 8 1/4", and 9 1/2" respectively from the bottom of the arrester and the test repeated as described above. Each of the four different size baffles were checked in this manner using the 530 feet per minute air velocity. After completing all of the tests using the different size baffles at different heights from the bottom of the arrester with the 530 feet per minute air velocity, the same series of tests were repeated using air velocities of 853, 1114, and 1510 feet per minute. All of the data are shown in Tables 15, 16, 17, 18, and the effect of the different size baffles upon the velocity of the air is graphically represented in Figure 29.

<u>Discussion of results</u>. From the data in Tables 15 through 18 it is possible to determine the correct location of any size of baffle tested, both from the amount of pressure produced and the resistance offered to the flow of the air. The different locations of the baffle did not produce a great difference in the velocity of the air for any given open

TABLE 15

The Effect of Size and Location of Baffle in a No. 3 Arrester upon the Flow of Air in a Chimney with Air Velocity in Open Chimney 530 ft./min.

Size of Baffle 7 1/2 x 11 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.039	.039	.039	.039	.039	.040	392
4 1/2	.039	.039	.039	.039	.039	.038	412
5 3/4	.039	.039	.038	.039	.039	.039	417
7	.039	.039	.039	.039	.039	.039	430
8 1/4	.040	.040	.040	.040	.040	.040	417
9 1/2	.049	.049	.049	.049	.049	.049	370

Size of Baffle 7 x 11 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.040	.040	.040	.040	.040	.040	433
4 1/2	.034	.035	.034	.033	.033	.033	427
5 3/4	.033	.033	.034	.034	.035	.035	440
7	.038	.038	.039	.038	.037	.036	422
8 1/4	.040	.040	.040	.040	.040	.040	412
9 1/2	.045	.045	.045	.045	.045	.045	417

TABLE 15 (cont.)

Size of Baffle 5 1/2 x 9 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.030	.030	.030	.030	.030	.030	435
4 1/2	.030	.030	.030	.030	.030	.030	447
5 3/4	.036	.036	.036	.035	.034	.034	445
7	.029	.029	.029	.029	.029	.029	445
8 1/4	.030	.030	.030	.030	.030	.030	445
9 1/2	.039	.039	.039	.039	.038	.038	437

Size of Baffle 4 1/2 x 8 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.029	.029	.028	.027	.027	.027	440
4 1/2	.021	.021	.021	.021	.021	.021	457
5 3/4	.020	.020	.021	.020	.020	.020	457
7	.024	.024	.024	.024	.024	.024	462
8 1/4	.022	.022	.022	.022	.022	.022	455
9 1/2	.029	.029	.029	.029	.029	.028	445

TABLE 16

The Effect of Size and Location of Baffle in a No. 3 Arrester upon the Flow of Air in a Chimney with Air Velocity in Open Chimney 853 ft./min.

Size of Baffle 7 1/2 x 11 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.086	.087	.086	.085	.084	.084	650
4 1/2	.080	.080	.080	.080	.080	.080	662
5 3/4	.080	.080	.080	.080	.080	.079	665
7	.080	.081	.081	.081	.081	.081	660
8 1/4	.087	.088	.088	.088	.087	.088	675
9 1/2	.098	.099	.098	.098	.097	.097	622

Size of Baffle 7 x 11 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.080	.080	.080	.080	.080	.080	632
4 1/2	.079	.078	.078	.078	.078	.076	662
5 3/4	.079	.079	.079	.078	.078	.078	660
7	.080	.080	.080	.080	.080	.080	662
8 1/4	.086	.086	.085	.084	.084	.084	665
9 1/2	.094	.095	.096	.096	.095	.093	637

TABLE 16 (cont.)

Size of Baffle 5 1/2 x 9 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.070	.070	.070	.070	.070	.070	657
4 1/2	.070	.070	.070	.070	.070	.070	672
5 3/4	.070	.070	.070	.069	.069	.070	685
7	.070	.070	.070	.070	.070	.070	667
8 1/4	.074	.074	.072	.071	.070	.071	642
9 1/2	.080	.080	.080	.079	.079	.079	647

Size of Baffle 4 1/2 x 8 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.060	.060	.060	.060	.060	.060	682
4 1/2	.060	.060	.060	.058	.058	.058	692
5 3/4	.060	.060	.060	.060	.060	.060	697
7	.060	.060	.060	.060	.060	.060	700
8 1/4	.064	.068	.068	.065	.065	.066	685
9 1/2	.070	.070	.070	.070	.070	.070	672

TABLE 17

The Effect of Size and Location of Baffle in a No. 3 Arrester upon the Flow of Air in a Chimney with Air Velocity in Open Chimney 1114 ft./min.

Size of Baffle 7 1/2 x 11 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.147	.146	.146	.143	.143	.143	825
4 1/2	.139	.139	.139	.139	.139	.139	858
5 3/4	.140	.140	.139	.139	.139	.139	838
7	.140	.140	.140	.140	.140	.140	838
8 1/4	.149	.149	.149	.149	.149	.149	805
9 1/2	.160	.160	.160	.160	.160	.160	733

Size of Baffle 7 x 11 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.139	.137	.136	.136	.136	.138	818
4 1/2	.130	.130	.130	.130	.130	.130	855
5 3/4	.130	.130	.129	.129	.129	.130	853
7	.130	.130	.130	.130	.130	.130	832
8 1/4	.140	.140	.139	.139	.140	.140	858
9 1/2	.151	.151	.151	.152	.152	.151	720

TABLE 17 (cont.)

Size of Baffle 5 1/2 x 9 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.125	.126	.124	.122	.123	.121	860
4 1/2	.128	.126	.123	.123	.123	.123	888
5 3/4	.126	.127	.127	.123	.126	.126	888
7	.129	.129	.128	.127	.128	.129	900
8 1/4	.133	.132	.132	.131	.122	.131	880
9 1/2	.141	.140	.141	.140	.140	.140	823

Size of Baffle 4 1/2 x 8 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.121	.121	.121	.120	.120	.120	938
4 1/2	.118	.119	.118	.117	.114	.115	978
5 3/4	.119	.119	.119	.119	.118	.117	1008
7	.119	.119	.119	.118	.117	.117	965
8 1/4	.120	.120	.120	.118	.118	.118	962
9 1/2	.127	.126	.126	.124	.124	.125	898

TABLE 18

The Effect of Size and Location of Baffle in a No. 3 Arrester upon the Flow of Air in a Chimney with Air Velocity in Open Chimney 1510 ft./min.

Size of Baffle 7 1/2 x 11 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney						Ft. per Min. Air Velocity with Arrester
	1	2	3	4	5	6	
3 1/4	.170	.170	.167	.165	.165	.165	930
4 1/2	.162	.165	.162	.160	.160	.160	938
5 3/4	.170	.168	.167	.160	.160	.160	955
7	.180	.180	.180	.174	.177	.175	953
8 1/4	.177	.177	.177	.175	.175	.175	920
9 1/2	.181	.181	.181	.180	.181	.181	867

Size of Baffle 7 x 11 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney						Ft. per Min. Air Velocity with Arrester
	1	2	3	4	5	6	
3 1/4	.177	.177	.170	.172	.172	.172	927
4 1/2	.170	.170	.170	.167	.170	.171	980
5 3/4	.175	.172	.170	.167	.165	.167	953
7	.168	.168	.168	.167	.170	.173	905
8 1/4	.178	.177	.175	.170	.172	.170	927
9 1/2	.181	.180	.180	.176	.179	.179	877

TABLE 18 (cont.)

Size of Baffle 5 1/2 x 9 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.168	.166	.165	.160	.167	.165	933
4 1/2	.163	.160	.161	.160	.164	.159	954
5 3/4	.163	.165	.160	.159	.161	.160	1000
7	.168	.171	.165	.164	.166	.164	990
8 1/4	.171	.170	.170	.167	.168	.169	967
9 1/2	.180	.180	.179	.177	.178	.178	895

Size of Baffle 4 1/2 x 8 1/2 Inches

Baffle Height in Inches	Pressure in Inches of Water at Different Locations in Chimney: 1	2	3	4	5	6	Ft. per Min. Air Velocity with Arrester
3 1/4	.160	.157	.150	.149	.150	.150	1055
4 1/2	.149	.148	.144	.145	.148	.149	1060
5 3/4	.154	.153	.148	.145	.149	.143	1073
7	.154	.154	.151	.148	.148	.147	1055
8 1/4	.159	.159	.154	.152	.155	.153	1040
9 1/2	.168	.168	.164	.165	.165	.166	985

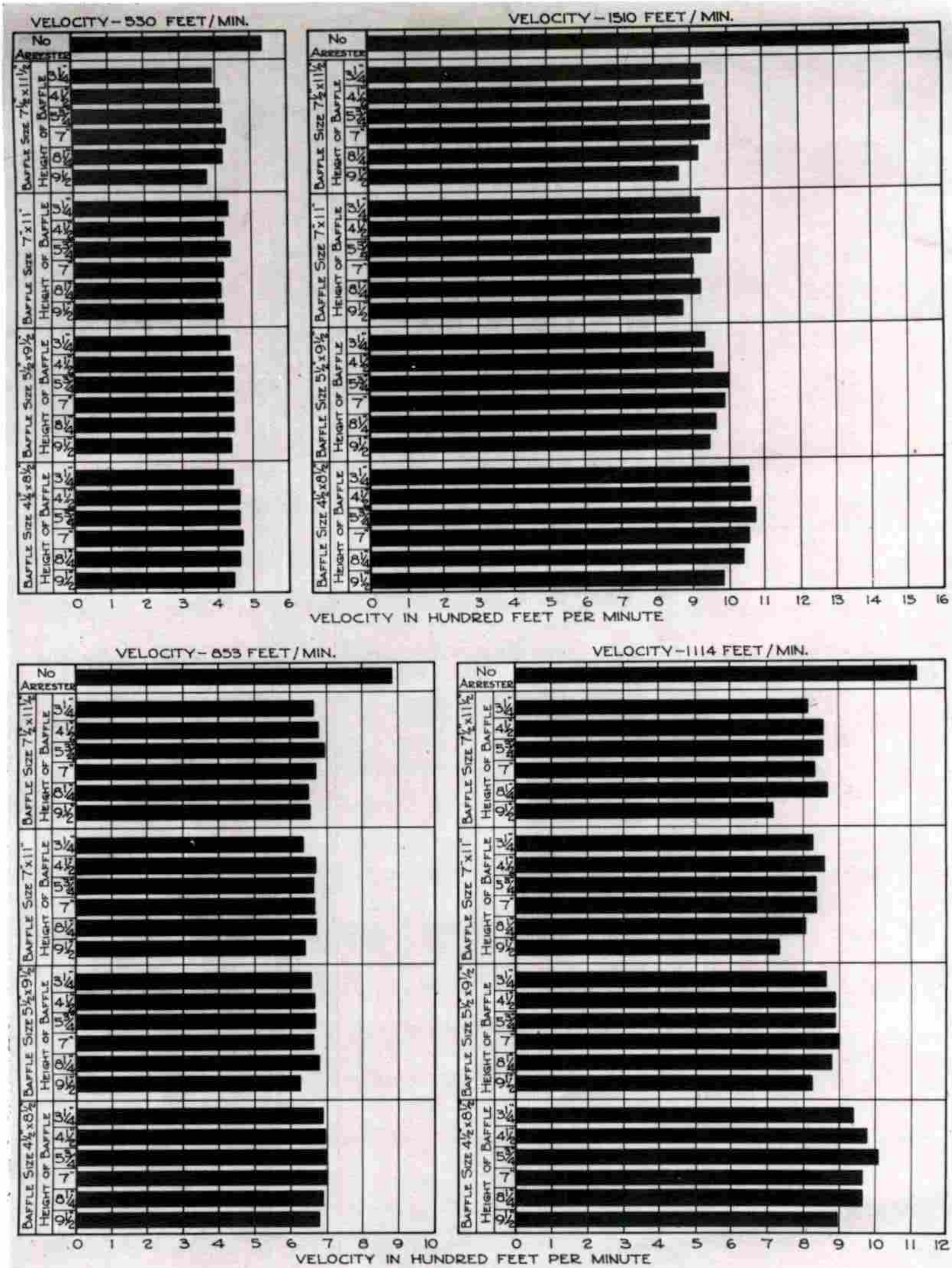


FIG. 29. THE EFFECT OF DIFFERENT SIZE AND LOCATION OF BAFFLE IN A NO. 3 ARRESTER UPON FOUR DIFFERENT VELOCITIES OF AIR FLOWING THROUGH A MODEL CHIMNEY.

chimney velocity; however, there was a decided decrease in the velocity when the arrester was placed 9 1/2 inches above the top of the chimney. The velocity of the air increased as the size of the baffle decreased.

The pressure in the chimney was greatest when the baffle was located 3 1/4, 8 1/4 and 9 1/2 inches above the top of the arrester. Higher velocity readings and lower pressure readings were obtained when the baffles were located 4 1/2, 5 3/4, and 7 inches above the top of the chimney.

Summary and conclusions

1. The results of the test, using partially clogged arresters on the small model chimney, were not very significant.

2. The pulsating flow of the air gave considerable trouble.

3. The chimney was not of uniform cross section.

4. When partially clogged spark arresters were tested on the large model chimney the velocity of the air in the chimney was reduced as much as 8.6 per cent when the 580 feet per minute velocity was used.

5. The pressure inside the chimney was constant throughout the height of the chimney when completely clogged spark arresters were used.

6. As the velocity of the air in the chimney increased the pressure readings also increased.

7. The clogged spark arresters greatly decreased the velocity of the air flowing through the arrester.

8. Velocities of 425, 570, and 805 feet per minute did not produce any significant differences in the per cent of the open chimney velocities.

9. Velocities of 570 and 805 feet per minute gave best results.

10. Arresters Nos. 1, 2, 3, and 4 gave best results throughout the tests using completely clogged arresters.

11. When the baffles in a No. 3 arrester were located 9 1/2 and 3 1/4 inches above the top of the chimney the velocity of the air was greatly decreased.

12. Baffles located 4 1/2, 5 3/4, and 7 inches above the top of the chimney gave best results.

13. The velocity of the air was decreased as the size of the baffle increased.

14. The tests using the large model chimney gave good results.

15. Tests should be made using a natural draft chimney where hot gases will be used rather than cold air.

16. A comparison should be made between the results obtained using the model chimney and the results of the tests using a natural draft chimney to determine whether or not

there is any correlation between the two tests.

The Effect of Spark Arresters upon the Flow of Gases in a Natural Draft Chimney

Even though spark arresters have become increasingly popular for use in preventing the escape of dangerous soot particles, they do under certain conditions interfere with the performance of the chimney. The fact that some of the spark arresters which are in use have given some trouble from clogging and interfering with the performance of chimneys has been a source of bitter criticism against the use of spark arresters. To be able to answer the following question - To what extent and under what conditions will a spark arrester interfere with the performance of a chimney? - formed the basis for this investigation.

Objectives of the investigation

The principal objective of this investigation was to study the characteristics of a natural draft chimney while it was operating under normal conditions and to study the characteristics of the same chimney while it was equipped with a spark arrester which was synthetically clogged. The study was conducted in an effort to determine the following:

1. The effect of clogged spark arresters upon the temperature of the flue gases at different heights in a chimney

2. The effect of clogged spark arresters upon the flow of gases in a chimney

3. The effect of spark arresters upon the available draft in a chimney

Equipment used in making the investigation

Test chimney. The natural draft chimney which was used throughout this part of the investigation was available in room 158 of the Agricultural Engineering Laboratory. The chimney had the common 2 x 2 1/2 brick outside dimensions, a height of 19'-8" and extended three feet above the roof. The inside dimensions of the terra cotta flue lining, which extended to a height of 17'-2", was 6 1/2" x 11". For the remaining 2'-6" the opening enlarged to 9" x 13". The top of the chimney was removed down to the top of the original flue lining. Four feet of flue lining was then added to the 17'-2" making a total height of the chimney used in this investigation 21'-2". It was necessary to install the flue lining in order to give the chimney a uniform cross section throughout its height. Figure 30 shows a sectional sketch of the chimney. A draft gauge connection and thermocouple was installed at different heights of the chimney as shown in Figure 30.

Heater. An Ideal Vecto heater, Series No. PP9, as manufactured by the American Radiator Company, was used to furnish the supply of heat needed for the investigation.

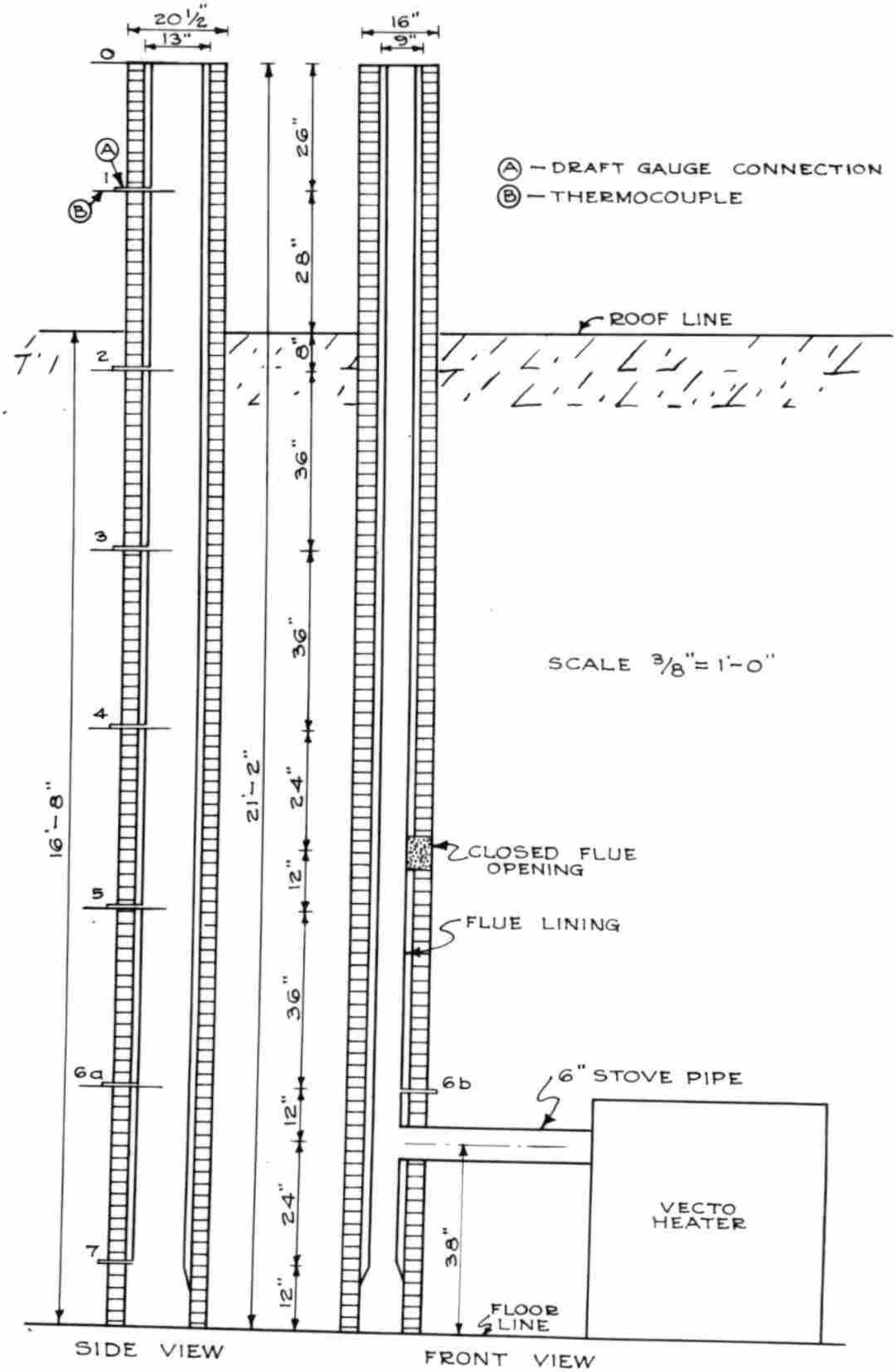


Fig. 30. SECTIONAL SKETCH OF BRICK TEST CHIMNEY

The heater was equipped with a gravity feed kerosene burner. With the use of this type burner it was possible to siphon the kerosene from a container; by doing this the quantity of fuel used per hour could be weighed very easily. The intake opening in the heater was equipped with a metal pipe 6" in diameter and 30" long. Figure 31 shows the metal pipe attached to the heater. The velocity of the air flowing through the pipe was measured by means of a thermocouple anemometer. Figure 32.

Draft gauge. The draft gauge used was one which has already been described and shown in Figure 11. The draft gauge was used to calibrate the multiple manometer tube which will be described in the following paragraph. The gauge was also used as a check on the accuracy of the manometer tube while it was in use.

Manometer tubes. The manometer tube was used to measure the draft or difference in pressure between a column of hot gases in a chimney and the outside air.

Construction of the U-shaped manometer tube is as follows: Two glass tubes approximately 1/4-inch in diameter and 30 inches long were mounted on a piece of 1/2" plywood. The bottom of the tubes were connected by means of a 3/8-inch rubber tube and a screw clamp made it possible to close the opening between the tubes. Two 7 1/2" x 7 1/2" x 2 1/2" tin pans were mounted above the tubes. In order to connect

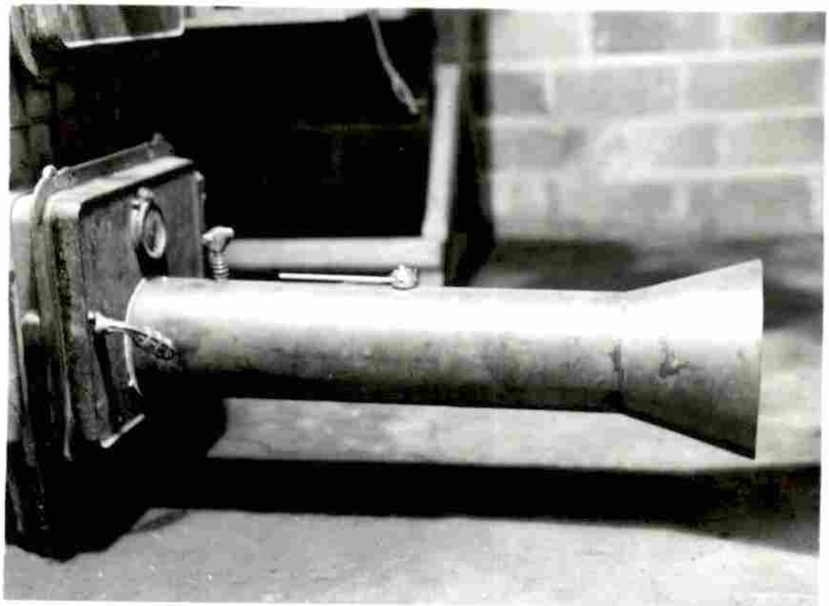


Fig. 31. Intake Pipe to Heater

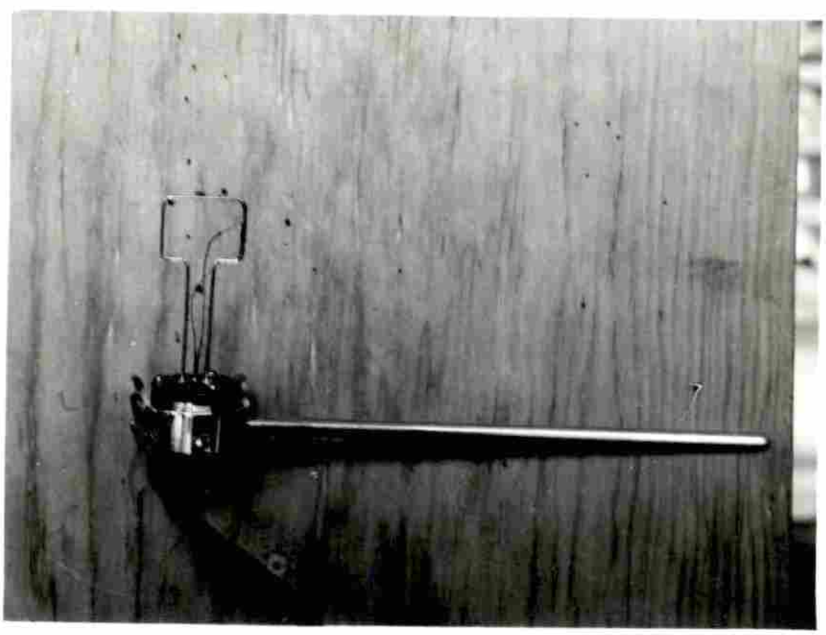


Fig. 32. Thermocouple Anemometer

the tin pans to the tubes it was necessary to solder a 1/2-inch copper tube 2 inches long to the bottom of each pan, the connection was then made by means of a 3/8-inch rubber tube. One of the pans was open to the air and the other pan was connected to the chimney; therefore, it was necessary that the top of one of the pans be made air tight except for a small 1/8-inch opening to which the connection was made to the chimney. The two pans were connected together by means of a 1/8-inch rubber tube connected to the 3/16-inch copper tubes which were soldered in the side of each pan. A screw clamp made it possible to close the opening between the pans.

In the use of the instrument two liquids of different densities were used; a mixture of water and methyl alcohol with specific gravity of 0.826 was used for the heavier liquid, and kerosene with specific gravity of 0.807 was used for the lighter liquid. In using the instrument the heavier liquid was first put into the tubes, care being exercised to avoid wetting of the top attachments; then the top connection between the tubes was opened and the lighter liquid poured into the tubes. While both pans were exposed to the air it was possible to balance the heavier liquid in most any position. As soon as the two liquids had reached an equilibrium the top connection was closed and the bottom connection was opened. As soon as the connection was made to the chimney the heavier liquid would flow toward the side of less pressure, a distance inversely proportional to the respective areas of the exposed surface of the tube and pans. Since the pans were so large in proportion to the opening in the tube, the heights of the liquid in the pans remained practically the same throughout the range of readings which were taken.

Eight of these U-shaped manometer tubes were mounted on a sheet of 1/2-inch plywood and mounted on the wall of the test room in such a way that the tubes could be tilted and all of the pans could be located together. Figure 33. The top of the heavier liquids were brought to the same heights and the series of U-shaped tubes were calibrated on a large sheet of white paper placed behind the tubes. The calibration was made by connecting a direct reading draft gauge in series with the tubes. After making the calibration chart it was placed behind the tubes so that readings could be made direct.

The instrument was very sensitive and great care had to be exercised in keeping the liquids in equilibrium and to see that no air bubbles were formed in the tube connections. Since the instrument was calibrated by the use of a very sensitive draft gauge and the calibrated chart was arranged so that readings could be made direct, no calculations were necessary. However, the difference in pressure could have been calculated by the use of the following equation:

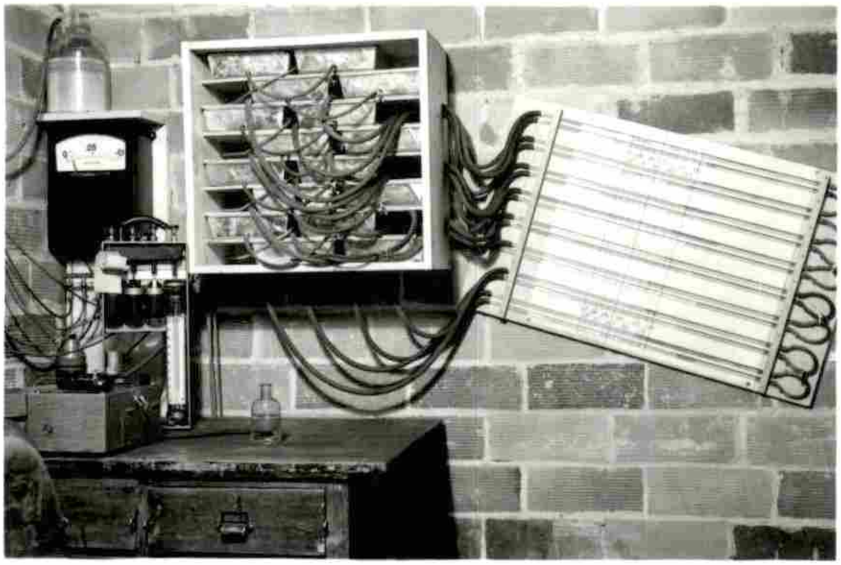


Fig. 33. Equipment Used in Testing Natural Draft Chimney

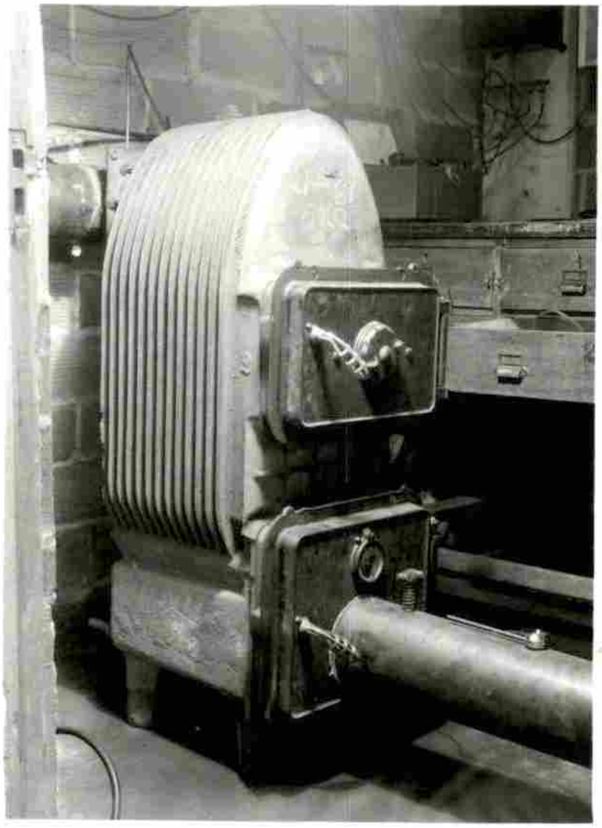


Fig. 34. Heater Used in Making Test

$$p - p' = h'd' - hd$$

or, $$p - p' = h\,(d' - d) \text{ if } h' \text{ is equal to } h$$

where p = pressure of the atmosphere

p' = pressure of the gases to be measured

h = difference in height measured from the lower surface of the heavier liquid

d' = density of the heavier liquid

d : density of the lighter liquid

The manometer tubes, Figure 33, were connected to the chimney as follows: 3/16" copper tubes were located in the chimney so that the end of the tube would be even with the inside wall of the chimney, Figure 30. The copper tubing was securely fastened to the side of the chimney and terminated at a point near the manometer tubes and draft gauge. Connections from the copper tubes to the manometer tubes and draft gauge were made by means of 1/8" rubber tubing.

The bottom tube of the manometer was connected to a point in the chimney 1' above floor level. There was no flow of air or gases past this point; therefore, the reading at this point served as a check against the readings at other points where there was a flow of gases. The top tube was left open to the atmosphere so that any difference in pressure within the room could be detected very readily. The rest of the tubes were connected to points in the chimney as shown in Figure 30. Readings from bottom to top of the chimney are shown by bottom to top tubes of the manometer.

The manometer tube was very sensitive and gave readings which check with a sensitive draft gauge. The kerosene which was used for the lighter liquid gave some trouble by causing the rubber tubes to deteriorate very rapidly. Only one tube had to be replaced during the test but the fact that the rubber tubes stretch made it necessary to balance the two liquids before each series of tests. The tubes were so arranged that they could be moved back and forth to bring the heavier liquid to zero. The liquid in each tube could be balanced by changing the quantity of lighter liquid on each side of the tube. A small eye dropper proved very useful in performing this task.

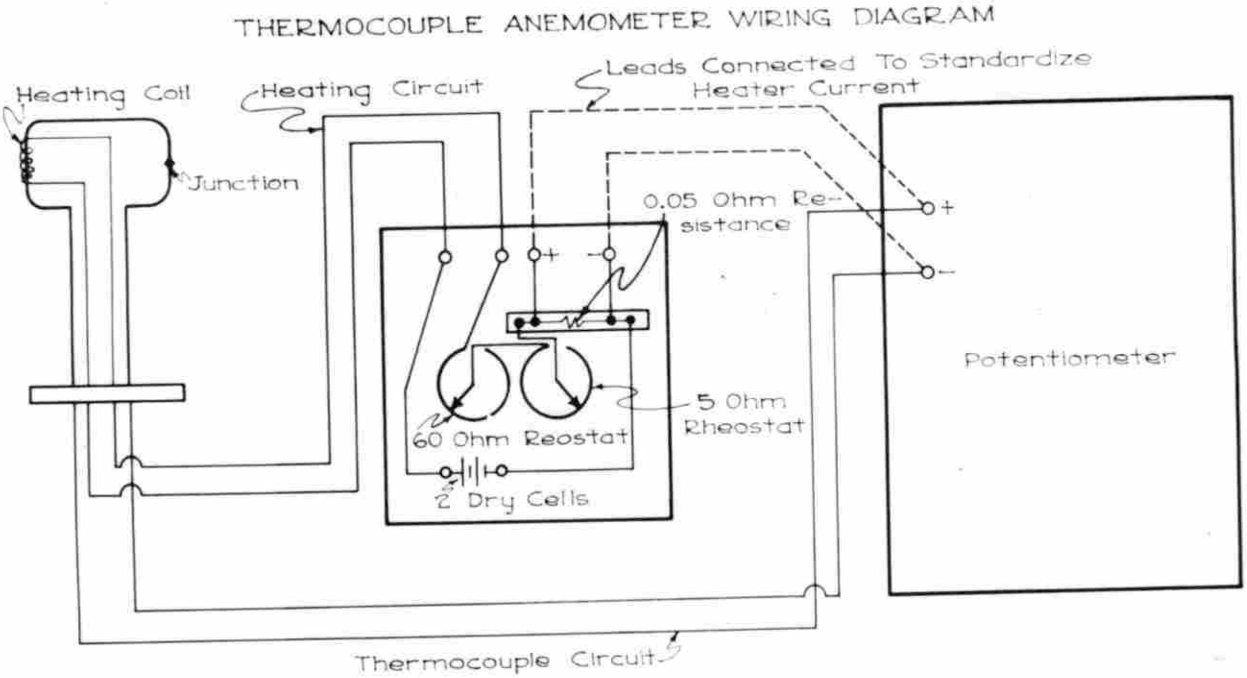
Velometer. The velometer was the same as that previously described in this manuscript except for the fact that in the case of this test a No. 2420 jet was used instead of the No. 2425-18.

Potentiometer. A No. 8662 portable precision potentiometer indicator with ranges 0-7.5 MV. and 0-75.0 MV. was used to read the temperature in the chimney at different heights and also to read the electromotive force from the thermocouple anemometer. The instrument was accurate within the limits of .01 MV. on the low range and .05 MV. on the high range. Automatic reference junction compensation was provided and temperature readings up to 250 degrees Fahrenheit could be read directly on the scale. For us in indicating temperatures higher than 250 degrees Fahrenheit it was necessary to use a thermos bottle filled with ice for the reference junction. All of the readings reported in this manuscript were taken when an ice bottle was used for the reference junction. Figure 36 shows a wiring diagram for the thermocouple circuit.

Thermocouple anemometer. The velocity of the air flowing through the intake of the furnace was measured by means of a thermocouple anemometer and the potentiometer indicator. This unit, Figure 35, consists of three parts: the potentiometer, batteries and resistances for heater, and the wire anemometer element. The operation of the anemometer is essentially the same as that of a thermocouple. One junction of iron-constantan wire is heated by a heater coil while the other junction is cooled by the air. An electromotive force is generated and detected by the galvanometer. The millivolt readings obtained on the potentiometer may be converted into feet per minute by use of the conversion chart, Figure 37.

Thermocouples. Iron-constantan thermocouples were located at different heights in the chimney, Figure 30, and numbered consecutively from the top of the chimney. The thermocouple junctions were soldered together with silver solder. The thermocouples were all the same length and terminated at a point in the test room so that readings could be taken conveniently.

Vane anemometer. An anemometer, manufactured by the



Note:
Connections can be made with copper wire of any convenient size or length.

Fig. 35. Thermocouple Anemometer Wiring Diagram

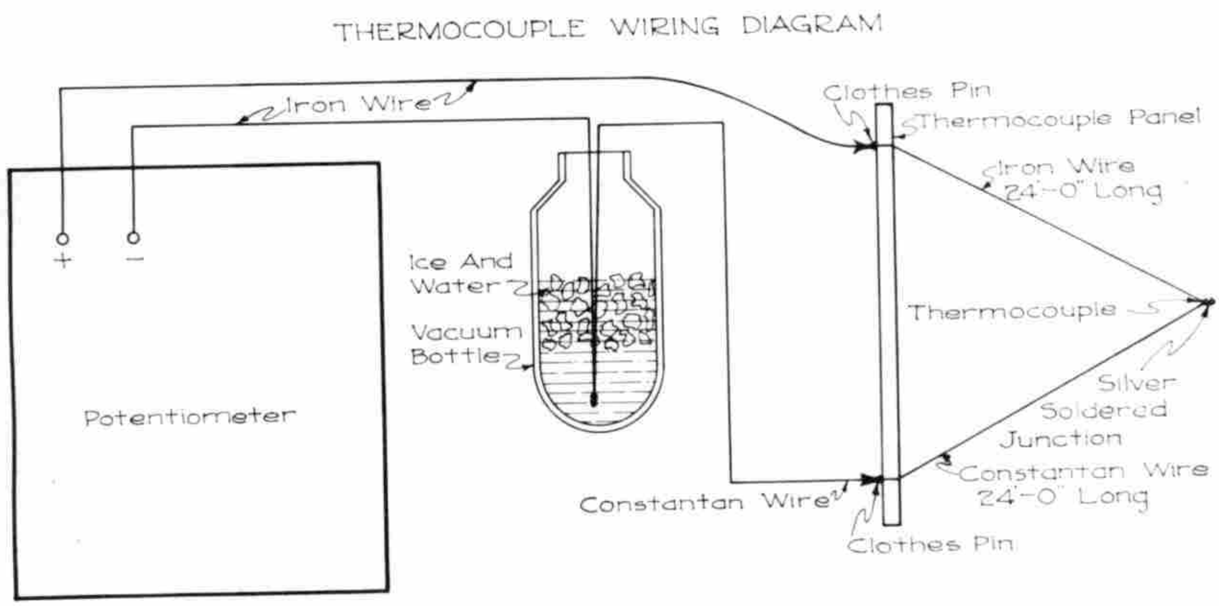


Fig. 36. Thermocouple Wiring Diagram

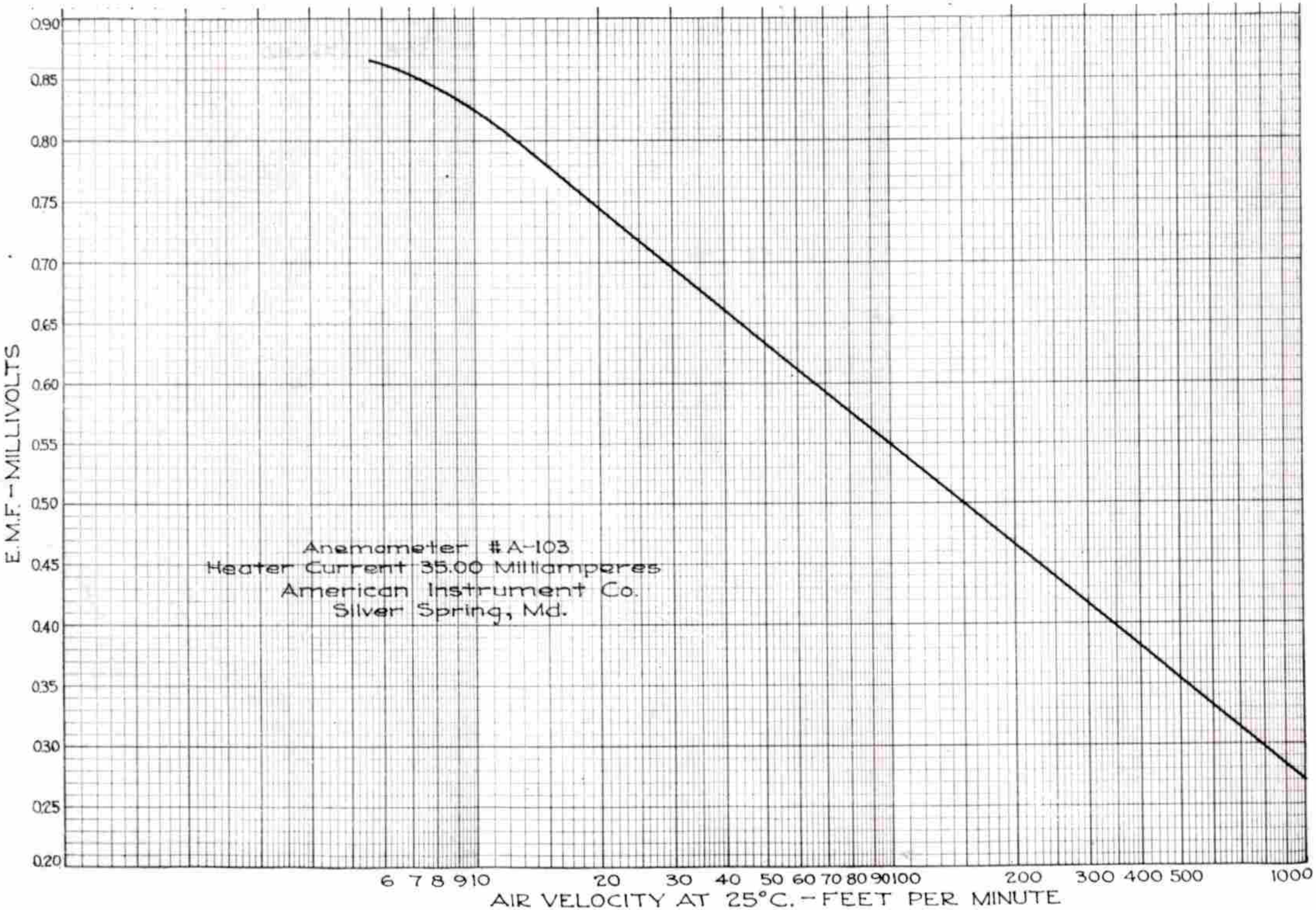


Fig. 37. Conversion Chart for Thermocouple Anemometer

Taylor Instrument Company, Rochester, New York, was employed to measure the velocity of the air currents within the chimney.

Spark arresters used in the investigation. The spark arresters used were completely clogged except for the free area and were the same as those previously described and used in testing the effect of clogged spark arresters upon the flow of air in a large model chimney.

A study of the characteristics of a natural draft chimney

A study of some of the operating characteristics of a natural draft chimney was necessary before attempting to investigate the effect of spark arresters upon the flow of gases. All efforts were directed in the first instance to a study of draft and the characteristics of chimneys which were already in use.

Draft. There are two kinds of draft according to the manner in which it is produced. They may be stated as follows:

1. Artificial draft
2. Natural draft

Artificial draft is produced mechanically by means of fans or blowers, and natural draft is produced by means of a chimney and heat. This part of the investigation will be devoted to a study of natural draft chimneys.

Natural draft. Natural draft is the difference in pressure produced by the difference in weight between the hot air or gases inside the chimney and an equal column of outside air.

Natural draft may be subdivided into three separate and distinct divisions, each of which has its own meaning. The subject will be discussed as follows in order that the specific problem which is to be discussed later may be more clearly understood.

Theoretical draft is the maximum difference in pressure when the chimney gases are stationary and there is no flow or circulation within the chimney, when the chimney gas temperature is at its maximum, and when the chimney itself is at its maximum height. Theoretical draft is purely a theoretical quantity and cannot be measured accurately by a measuring device.

Available draft is the theoretical draft less the amounts lost by the velocity of the chimney gases and also by the friction of the chimney gases on the interior walls of the chimney. Available draft is the difference in pressure as measured by a draft gauge when the chimney is operating and the chimney gases are flowing freely.

Required draft is the sum of the draft losses through the fuel bed, boiler, turns and breeching.

Since the available draft may be measured very readily by means of a draft gauge the influence of spark arresters upon the available draft in a chimney will be discussed in this manuscript.

Preliminary test No. 1. Before attempting to set up any testing apparatus it was decided to make some preliminary investigations on a chimney which was operating under ordinary conditions. The chimney selected for this preliminary test was 2 x 2 1/2 brick in size and 35 feet high. A Quick Heater, Series F, No. 26, as manufactured by the Quick Heater and Supply Company, Des Moines, Iowa, was connected to the chimney by means of a 7" pipe which terminated in the chimney at a height of 4 feet above the basement floor. Air entering the breeching and furnace was regulated by means of dampers.

The testing procedure was as follows: A 3/4" x 1/2" hole was drilled into the side of the chimney 24 feet above the grate level in the furnace. This opening was large enough to receive the 2425-18 jet for reading the velocity of the gases inside the chimney direct. Another hole was drilled into the chimney to receive the draft gauge connection. The draft gauge No. 1-DL-1 was connected to the opening in the chimney by means of a 1/8" copper tube which was sealed in the opening in the chimney and connected to the draft gauge by means of 1/8" rubber tubing.

Results of the readings taken indicate that the velocity and static pressure varied considerably. The velocity varied from 350 to 400 feet per minute and the static pressure varied from -.015 to -.020 inches of water when there was a hot bed of coals in the furnace and the intake opening in the furnace was closed. An etched stem thermometer which was inserted in the chimney at the same height showed the temperature to be 171 degrees Fahrenheit. A second reading was taken when the intake door to the furnace was open. The static pressure or draft varied from -.020 to -.025 inches of water and the velocity of the gases varied from 250 to 300 feet per minute. All of the readings were taken near the middle of the day, so in order to get more data a reading was taken early in the morning after the furnace had been fired very heavily. The pressure was found to vary from -.03 to -.035 inches of water and the temperature was too high to be recorded by the 220 degree thermometer.

Preliminary test No. 2. In this test a chimney 8 inches in diameter and approximately 24 feet high was used. The material used in construction of the chimney was heavy sheet metal, around which was wrapped a thin sheet of asbestos. Even though the chimney was made of sheet metal the performance should be essentially the same as one constructed of brick except for the fact that the heat loss would probably be a little greater.

An ideal Vecto Heater, Series No. PP9, as manufactured by the American Radiator Company, was connected to the 8-inch flue by means of an expanded joint.

The testing procedure was as follows: Small 3/32-inch holes were drilled in the chimney, and over each hole was soldered a 3/16-inch copper tube 2 inches long to make a suitable connection for the draft gauge. The holes and draft gauge connections were located as follows: one just outside the heater; one 3 feet, 8 feet, and 13 feet above the burner in the heater. The draft gauge was connected to the openings by means of 1/8-inch rubber tubes. A 15/64-inch hole was drilled in the flue 8 feet above the heater to receive the etched stem thermometer.

The heater was set in operation and the air allowed to enter the heater was regulated to insure proper combustion of the fuel. After the heater had been in operation for one hour, pressure readings were taken at the different openings in the flue which were numbered consecutively from the top of the heater. The draft gauge reading in inches of water for location No. 1 was -.053; for location No. 2, -.045; for location No. 3, -.025; and for location No. 4, -.017.

The temperature in the flue was increased by allowing more fuel to enter the burner. The temperature could not be measured with the thermometer but it was hot enough to melt the soldered joint just outside the heater. The draft reading in inches of water for location No. 2 was -.056; for location No. 3, -.030; and for location No. 4, -.025.

Summary and conclusions.

1. The greatest negative static pressure in a natural draft chimney is at the bottom nearest the source of heat.

2. The static pressure varies considerably in a natural draft chimney.

3. The velocity of flue gases fluctuates very widely in a natural draft chimney.

4. The velocity of the gases is greatest when the temperature difference is greatest.

5. Wind blowing over the top of the chimney has a great influence upon the velocity of the flue gases and the available draft in a chimney.

6. The temperature in a chimney 24 feet above the furnace exceeds 220 degrees Fahrenheit when the air is allowed to enter underneath the grates and pass through a hot bed of coals.

7. Further study is necessary to determine:

   (a) Temperature of flue gases throughout height of chimney

   (b) Static pressure readings the full height of the chimney

<u>The effect of clogged spark arresters upon the flow of gases in a chimney</u>

Spark arresters after they have become clogged with soot may restrict the opening in the chimney and effect the flow of the gases. The objective of this series of tests was to determine the effect of clogged spark arresters upon the flow of gases in a natural draft chimney while it is operating under normal conditions.

Equipment used in the test. The equipment used in making the tests consisted of the test chimney, heater, vane anemometer and clogged spark arresters.

Testing procedure. The fire was started in the heater and the flame was regulated for proper combustion. After the heater had been burning for four hours there was no noticeable change in the temperature gradient. Without making any changes in the adjustment of the burner a vane anemometer which was securely fastened to a piece of wood 8 inches long was mounted in the center and 12 inches from the top of the chimney. The piece of wood was wedged into a 1/2 x 3/4-inch hole which had been drilled in the side of the chimney. This offered sufficient support for the anemometer. A piece of wire wrapped around the stop lever on the anemometer and threaded through a groove in the handle of the anemometer made it possible to start and stop the anemometer from the outside of the chimney without having to remove the arrester from the top of the chimney.

The velocity of the gases in the chimney was checked for a five-minute period before an arrester was placed on the chimney. After an arrester was placed on the chimney the velocity was checked again for a five-minute period and recorded in table form. Each arrester was checked in this manner against the open chimney velocity and the data were recorded in Table 19, Test No. 1. The open chimney velocity shown in the tables is the average of three readings taken during the period of the test.

After completing Test No. 1 the amount of fuel allowed to enter the burner was increased. Thirty minutes later the open chimney velocity was checked and found to be 116 feet per minute. All of the arresters were checked again in the same manner as described for Test No. 1. The data were recorded in Table 20, Test No. 2.

A third test was made when the velocity of the gases in the open chimney was 103 feet per minute. The data for this test were recorded in Table 21, Test No. 3.

Results of test. An examination of the data in the columns titled per cent of open chimney velocity, indicates that the velocity of the flue gases was increased when some of the arresters were used. In Test No. 1 the No. 4 arrester did not affect the velocity of the gases at all. When the No. 10 arrester was used, the velocity was only 60.0 per cent; No. 9 was only 84.8, and the rest of the arresters gave velocities of more than 90 per cent of the open chimney velocity. In Test No. 2 all of the arresters except Nos. 6, 8, and 10 increased the velocity. In Test No. 3 arresters Nos. 6, 7, 9, and 10 were the ones which reduced the velocity.

Conclusions.

1. Arrester No. 10 reduced the velocity most in every

TABLE 19

The Influence of Spark Arresters Upon the Velocity of Gases in a Natural Draft Chimney

Test No. 1

Arrester Number	Velocity in Feet for Five Minute Period	Velocity in Feet per Minute	% of Open Chimney Velocity
1	448	89.6	96.4
2	424	84.8	91.1
3	425	85.0	91.4
4	465	93.0	100.0
5	426	85.2	91.6
6	454	90.8	97.6
7	440	88.0	94.6
8	429	85.8	92.2
9	394	78.8	84.8
10	325	65.0	69.9
No Arrester	465	93.0	

TABLE 20

The Influence of Spark Arresters Upon the Velocity of Gases in a Natural Draft Chimney

Test No. 2

Arrester Number	Velocity in Feet for Five Minute Period	Velocity in Feet per Minute	% of Open Chimney Velocity
1	602.5	120.5	103.9
2	625.0	125.0	107.8
3	617.5	123.5	106.0
4	607.5	121.5	104.8
5	592.5	118.5	102.1
6	575.0	115.0	99.1
7	590.0	118.0	101.7
8	570.0	114.0	98.2
9	595.0	119.0	102.6
10	510.0	102.0	88.0
No Arrester	580.0	116.0	

TABLE 21

The Influence of Spark Arresters Upon the Velocity of Gases in a Natural Draft Chimney

Test No. 3

Arrester Number	Velocity in Feet for Five Minute Period	Velocity in Feet per Minute	% of Open Chimney Velocity
1	519	103.8	100.5
2	515	103.0	100.0
3	537	107.4	104.2
4	539	107.8	104.5
5	515	103.0	100.0
6	505	101.0	98.0
7	509	101.8	98.7
8	530	106.0	102.9
9	507	101.4	98.5
10	447	89.4	86.6
No Arrester	515	103.0	

test.

2. Arrester No. 6 reduced the velocity in each test.

3. Most of the arresters increased rather than decreased the velocity of the gases.

4. No temperature correction was available for the vane anemometer, and even though the temperature at the anemometer did not exceed 150 degrees, some correction should have been made.

5. The tests should be used for comparison only.

The effect of clogged spark arresters upon the velocity of air passing through the intake of the heater

Since some of the clogged spark arresters increased the velocity of the flue gases in the tests just described, it was decided to continue the investigation and determine the effect of the clogged spark arresters upon the velocity of air passing through the intake of the heater.

Equipment used in the test. The equipment used in the test included the test chimney, heater, thermocouple anemometer, resistance box and potentiometer.

Testing procedure. Before starting the heater it was necessary to mount the thermocouple anemometer, Figure 32, in a 6-inch metal pipe 24 inches long and fasten the pipe securely over the intake opening below the burner in the heater, Figure 31. The pipe was funnel-shaped on one end for a length of 6 inches. The main section of the pipe was .65 of the area of the funnel on the end of the pipe. The funnel at the end of the pipe helped to insure a more uniform flow of air through the main section of the pipe. The thermocouple anemometer was located approximately in the center of the pipe and 17 inches from the mouth of the funnel. An ordinary 6-inch stove flue damper was placed in the pipe 3 inches from the heater.

As soon as the intake pipe was adjusted the burner was started and allowed to burn two hours before any readings were taken. While the chimney was approaching a uniform heat the thermocouple circuit, Figure 35, was set up and preliminary readings were taken to determine whether or not the flow of air through the pipe was uniform.

While the chimney was operating under normal conditions, the velocity of the air flowing through the intake pipe was found to be 500 feet per minute. Without making any changes in the adjustment of the heater or chimney, spark arresters of different types were placed on the chimney and the velocity of the air flowing through the pipe, with each arrester, was recorded in Table 22. Only the average of three readings is shown in the table.

The thermocouple anemometer did not give readings that could be read very closely. The reason for this was due to the fact that the potentiometer could be read only to

TABLE 22

The Effect of Clogged Spark Arresters upon the Velocity of Air Flowing Through the Intake of the Heater

Arrester Number	Velocity Through Intake ft./min.	Velocity Through Intake ft./min.
	first test	second test
1	520	127
Open	500	127
2	560	108
Open	500	108
3	520	180
Open	500	180
4	520	118
Open	500	118
5	520	108
Open	500	108
6	560	108
Open	500	108
7	560	108
Open	500	108
8	560	180
Open	500	180
9	480	127
Open	500	127
10	460	99
Open	500	108

.01 millivolt and estimated to .005 of a millivolt. This .005 millivolt difference for the range used on the conversion chart would be equivalent to approximately 20 feet per minute. Lower velocities could be read more accurately. A second series of tests are shown in Table 22.

Results of the test. All of the arresters except Nos. 9 and 10 increased the velocity of the air in the first test; however, when the test was repeated using lower velocities, there was no noticeable change in the velocity either with or without an arrester until No. 10 was used. Arrester No. 10 reduced the velocity 9 feet per minute.

The velocity of the gases in the chimney may be checked if the following factors are known:

1. Velocity of the air entering the heater
2. Temperature of the flue gases
3. Temperature of the air entering the heater
4. Quantity of fuel used per hour

It was decided to check the flue gas velocity readings already obtained to see if there was any comparison. Throughout the series of tests on the natural draft chimney the quantity of fuel used per hour was determined by weighing the amount of fuel used each hour. With this and the other factors already available, it was very easy to check the flue gas velocities. After placing the data in tabular form it was evident that spark arresters with a reasonable amount of free area will not affect the velocity of the gases. The No. 10 arrester, which was the only arrester without free area, did not interfere with the velocity of the gases.

An orsat outfit was used to check the analysis of the flue gases and from this analysis it was evident that the flue gases produced during the test contained a large percentage of air.

Conclusions. Further investigation is necessary in order to determine the effect of spark arresters upon the velocity of flue gases when the chimney is operating at full capacity.

The effect of clogged spark arresters upon the temperature and available draft in a chimney

The preliminary tests which were made revealed the fact that the temperature and available draft in a chimney was greatest near the bottom of the chimney. It was decided to investigate this occurrence still further and note the effects produced by placing different types of clogged spark arresters on the chimney while it was operating under normal conditions and when there was no outside wind blowing.

Equipment used in the test. Here again the test chimney and heater were used. The temperature was taken by means of thermocouples located in the chimney as shown by Figure 30. The thermocouples were read by means of the potentiometer. The available draft at different heights in the chimney was indicated by manometer tubes mounted as shown in Figure 33.

Testing procedure. Before any testing could be done it was necessary to let the temperature gradient in the chimney become uniform. To do this the furnace was allowed to burn for at least two hours; however, in the case of this test the burner was started in the early morning and it was 4:00 o'clock in the afternoon before the wind velocity was below three miles per hour and test readings could be made. Before any test readings were made with the manometer tubes, it was necessary to recheck the calibration against the 1-DL-1 Pointer Draft Gauge. Care was exercised to see that no air bubbles were formed in the tubes and that each tube would return to zero after a reading.

The manometer tubes were connected to the chimney in such a way that readings from the bottom to top tubes of the manometer gave readings from the bottom to the top of the chimney. The top pair of tubes was left open to the atmosphere.

While the chimney was operating under normal conditions and without an arrester, the temperature at different heights in the chimney was checked and recorded. Since the manometer tubes were mounted on the wall of the test room, it was only necessary to take a picture of the tubes to get the desired information about the available draft at different heights in the chimney. Figure 38 shows the available draft at different heights in the chimney when no arrester was used. Arresters of different types were then placed on the chimney. The temperature in the chimney for each arrester tested is shown in Table 23. A picture of the manometer tube readings for each arrester tested is shown in Figure 38.

At the conclusion of the test just described the burner was opened to increase the temperature in the chimney. The burner was allowed to operate at this setting for 30 minutes and at the end of this period the temperature at different heights in the chimney was constant. The available draft is shown by Figure 39. Immediately after the draft was checked the burner was cut off and the intake to the heater was sealed airtight. Five minutes later the draft was checked again. Figure 40 shows the available draft at the end of the five-minute period. Typical chimney temperature and draft or pressure curves are shown in Figure 41.

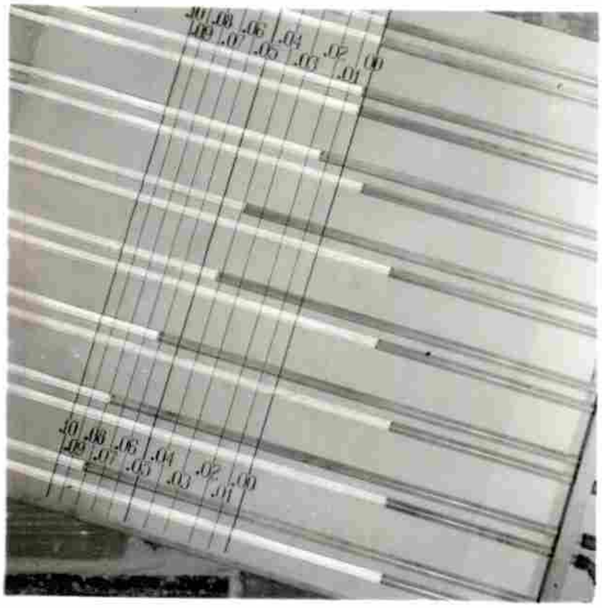
Results of the test. The effect of spark arresters upon the temperature in the chimney was not very significant. The temperature gradient in the chimney was affected by quantity of fuel used, completeness of combustion, temperature of outside air, temperature of air entering the heater, amount of air entering the heater, and the location of the chimney. If the chimney is located inside a warm building the temperature gradient will necessarily be different from the temperature gradient of the same chimney located where the cold outside air could strike it.

From the data in Figure 38 it is evident that the

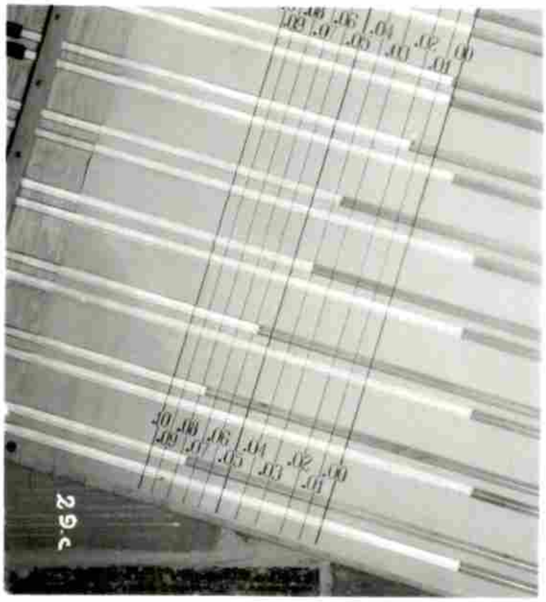
TABLE 23

Temperature in Chimney When Equipped with Different Types of Clogged Spark Arresters

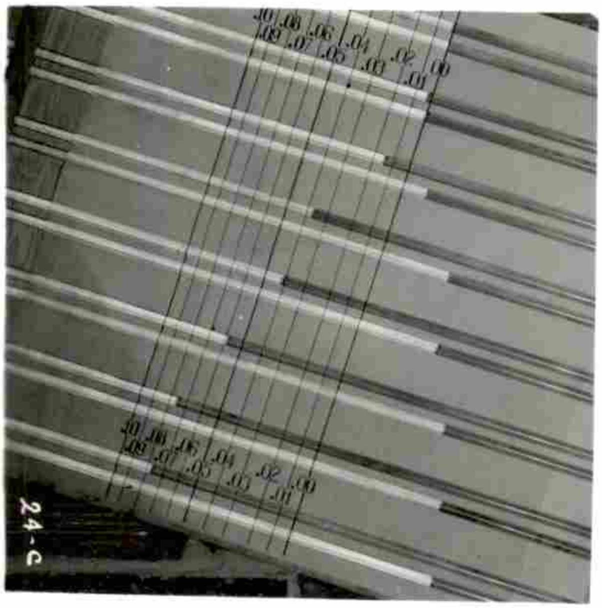
Arrester Number	Temperature at Different Locations in Chimney Degrees Fahr.						
	0	1	2	3	4	5	6
1	164	175	202	205	226	285	305
2	169	175	206	210	233	285	305
3	166	172	202	206	224	275	298
4	162	173	201	209	232	281	302
5	165	171	202	208	230	281	302
6	177	181	215	219	253	318	343
7	176	185	218	227	253	321	346
8	165	170	200	202	222	271	298
9	165	169	197	202	224	271	298
No Arrester	169	172	214	219	297	321	346



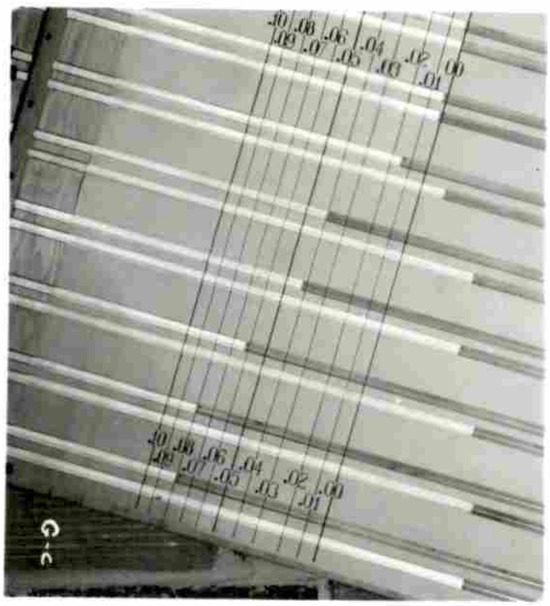
Open Chimney



Arrester No. 1

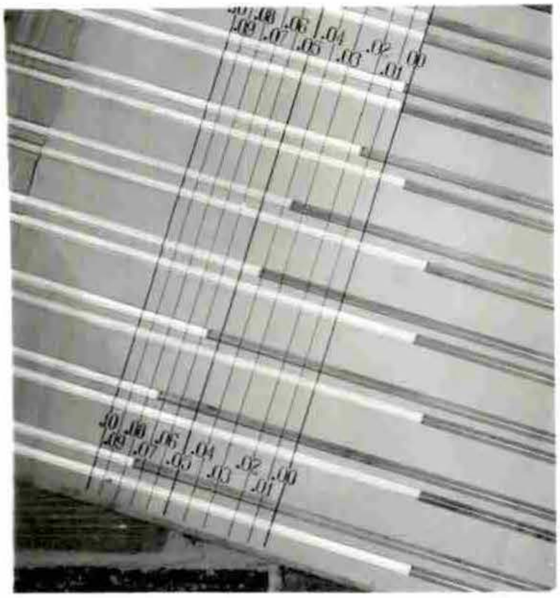


Arrester No. 2

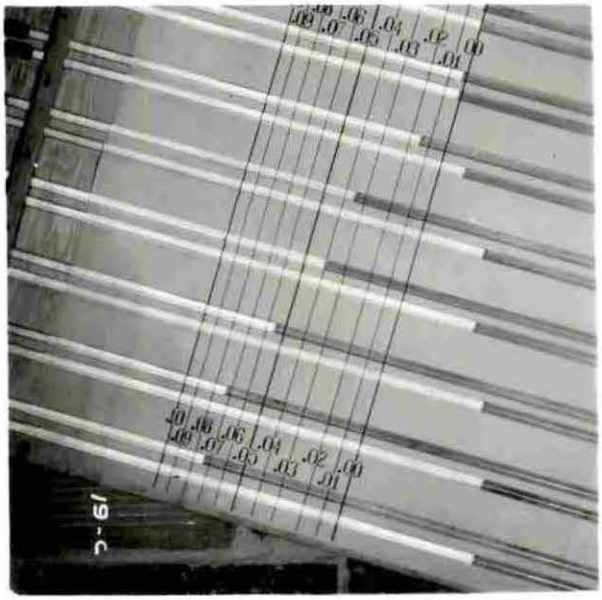


Arrester No. 3

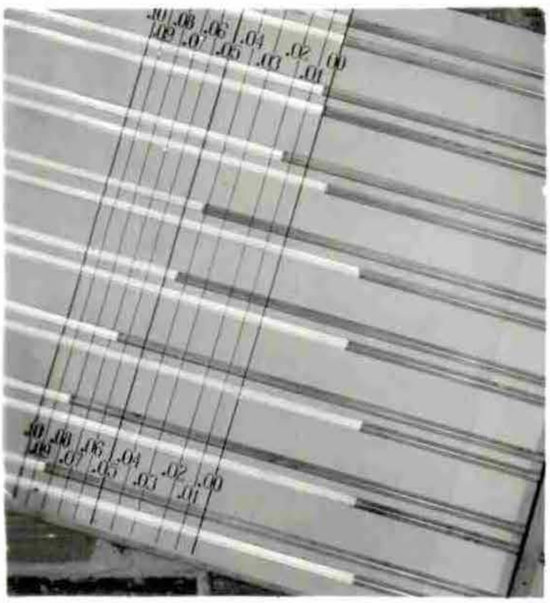
Fig. 38. Pressure Gradient in Chimney for Each Arrester Tested



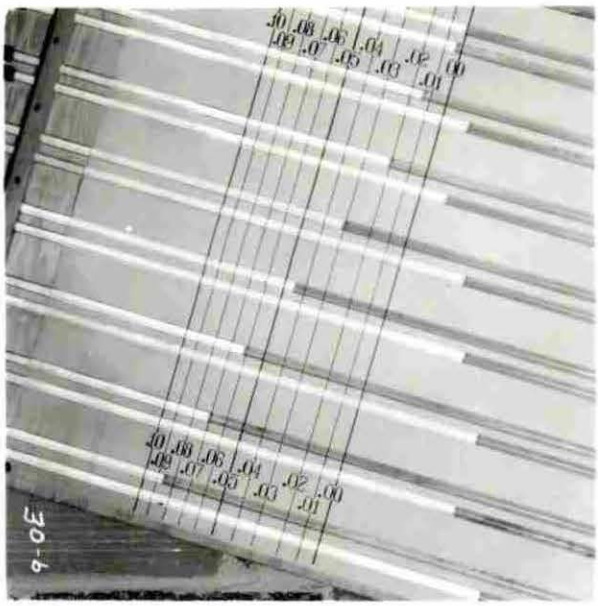
Arrester No. 4



Arrester No. 5

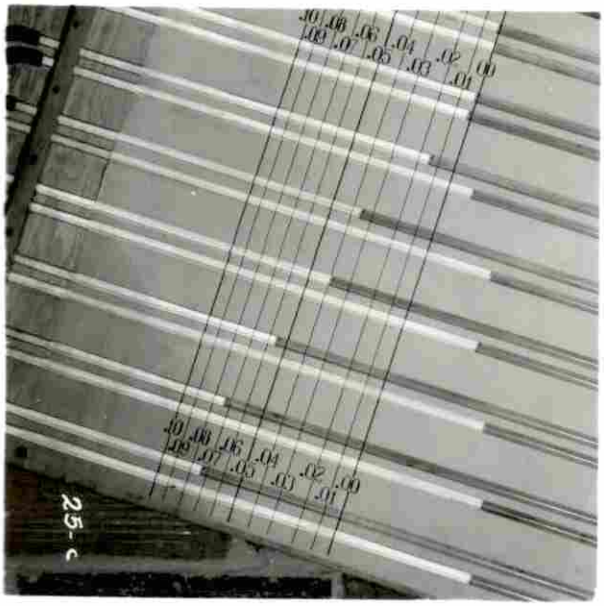


Arrester No. 6

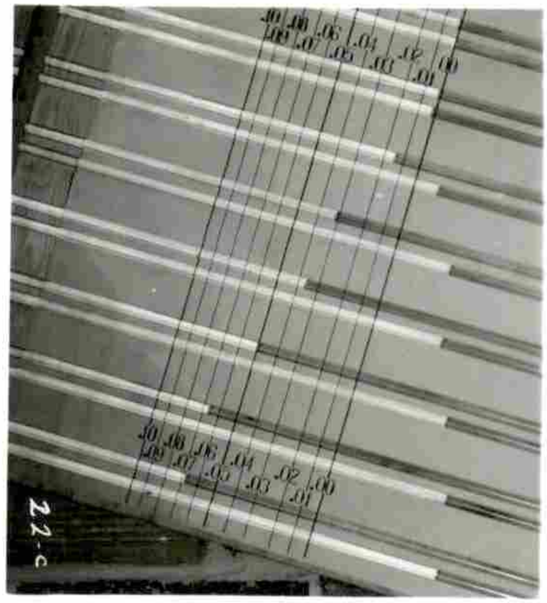


Arrester No. 7

Fig. 38 (cont.)



Arrester No. 8



Arrester No. 9

Fig. 38 (cont.)

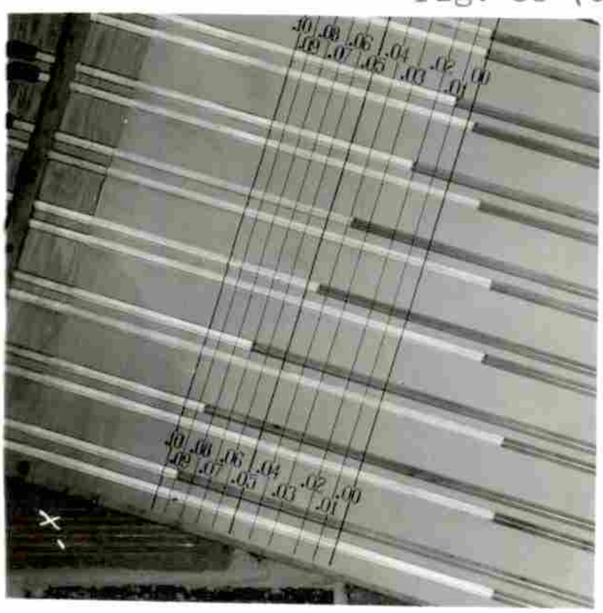


Fig. 39. Pressure Gradient When No Arrester Was Used

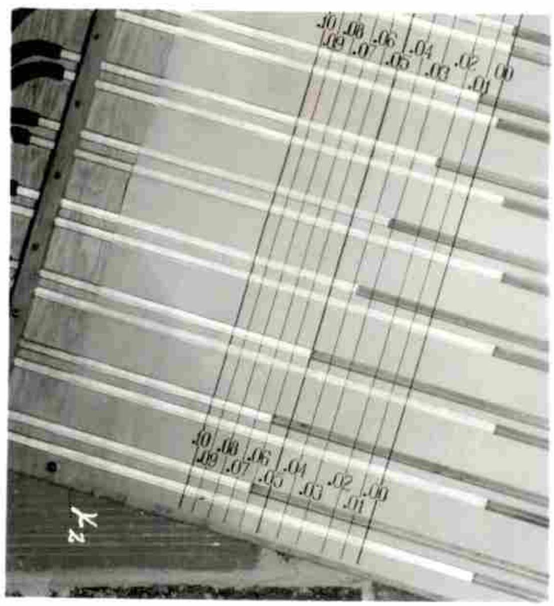


Fig. 40. Pressure Gradient 5 Minutes After Heater Was Cut Off

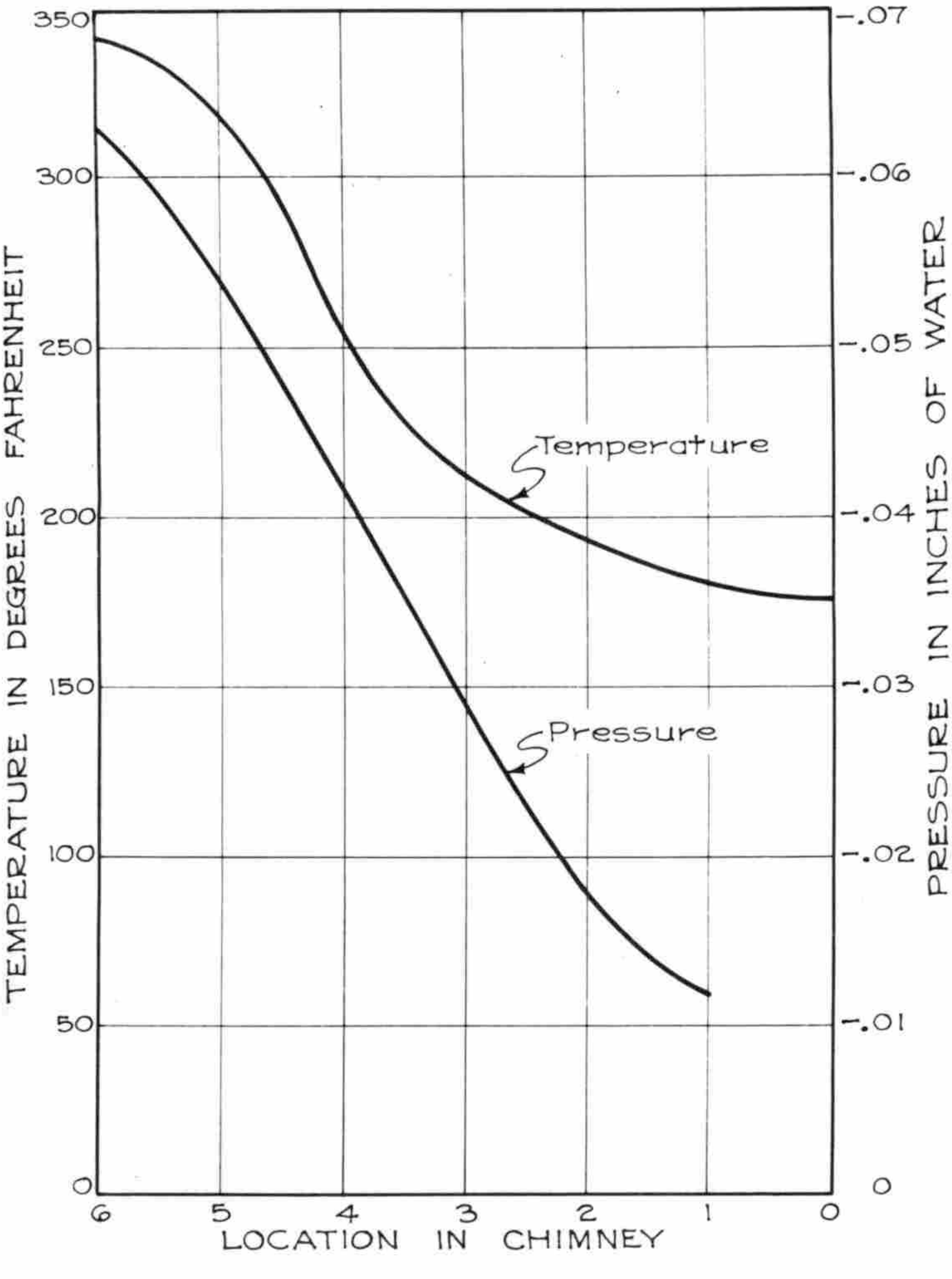


Fig. 41. TYPICAL CHIMNEY TEMPERATURE AND PRESSURE CURVES

arresters did not have an appreciable effect upon the available draft in the chimney. Arrester No. 9 decreased the draft more than any of the other arresters.

Figures 39 and 40 indicate very clearly that the available draft in a chimney depends upon the temperature inside the chimney. In the five-minute period the draft decreased -.03 inches of water

Conclusions.

1. The spark arresters did not influence the available draft or the temperature in the chimney a great deal. A slight decrease was noticed when all arresters were used except No. 7.

2. Arrester No. 9 showed the greatest decrease in available draft.

3. The average temperature during the test period varied from 168 degrees at the top of the chimney to 314 degrees at the bottom of the chimney.

4. The temperature in the chimney was affected by the temperature of the outside air and velocity of wind.

5. The temperature gradient will vary according to the temperature in the chimney.

<u>The effect of partially clogged spark arresters upon the available draft in a chimney when there is a wind velocity of 1400 feet per minute blowing into the arrester</u>

Careful observation throughout the previous investigations indicates that wind has a decided influence upon the performance of a chimney. This coupled with the statment made by Stanworth (15), "In one way or other winds are the cause of at least 90 per cent of smoky chimneys," has prompted this investigation.

<u>Set-up for testing</u>. The chimney and heater used in this investigation are the same as that used in the previous investigation and shown in Figure 30 except for the fact that the draft reading was taken at the discharge of the heater. The wind velocity was furnished by a 16-inch propeller mounted on a 1/4 horse power electric motor. A spark arrester clogged in one end and one-half of each side is shown by Figure 42. An arrester clogged in one corner and fan are shown in Figure 43. The velocity of the air forced into the arrester was determined by the use of the velometer equipped with a No. 2420 jet. Arresters which have been clogged only in one end and one-half of each side are shown in Figure 44.

<u>Testing procedure</u>. The heater was set in operation and regulated to maintain a constant temperature in the chimney when there was an arrester in place and when there was no side wind blowing. The available draft for this condition

Fig. 43. Spark Arrester Clogged in One Corner Ready for Test

Fig. 42. Spark Arrester Clogged in One End and One-half of Each Side Ready for Test

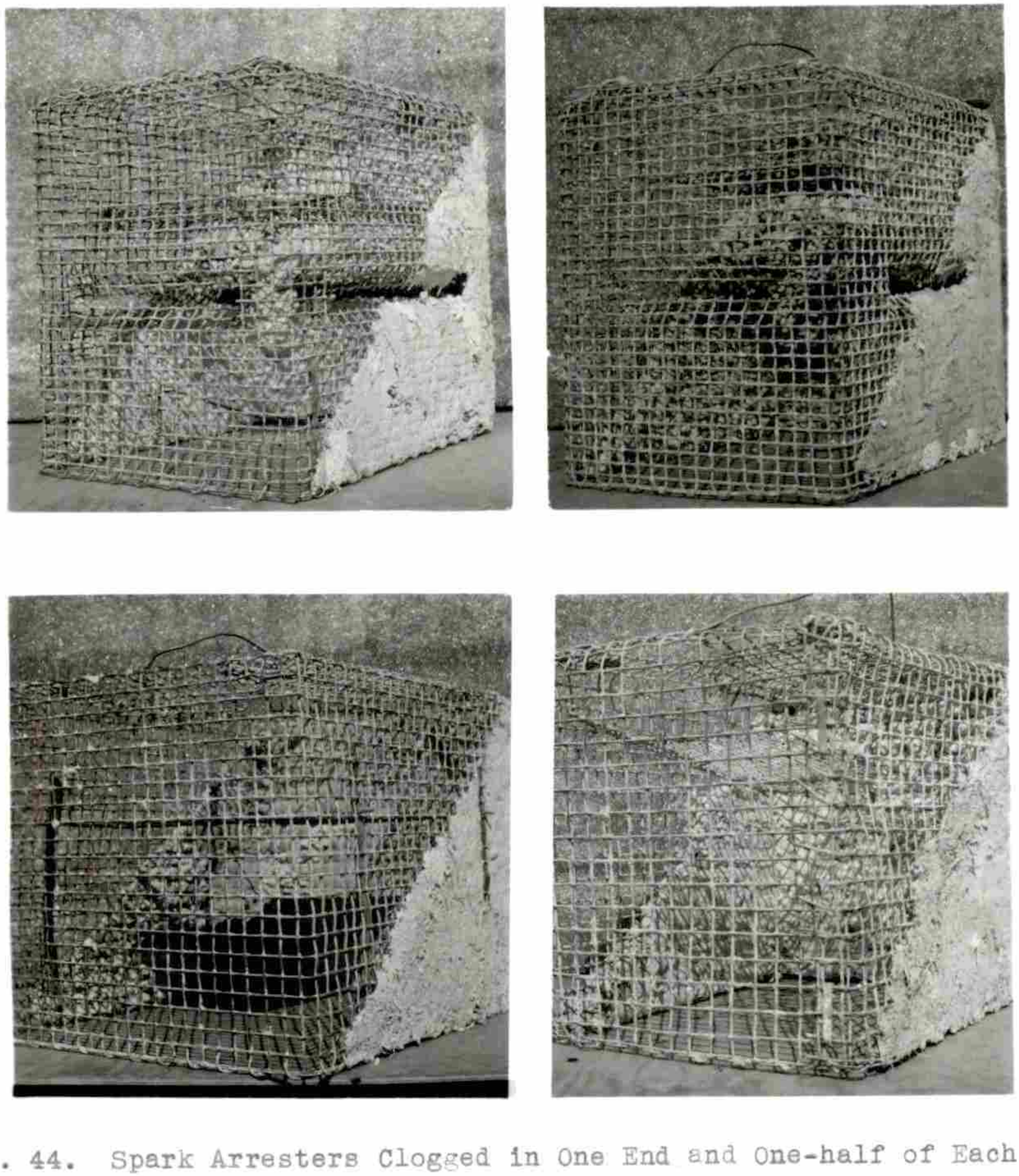


Fig. 44. Spark Arresters Clogged in One End and One-half of Each Side.

was recorded, then the fan was started and the draft at the end of two minutes was recorded. All of the data for the different types of spark arresters will be found in Table 24. In the first test the wind was directed in the end of the arresters, or in direction A, Figure 45.

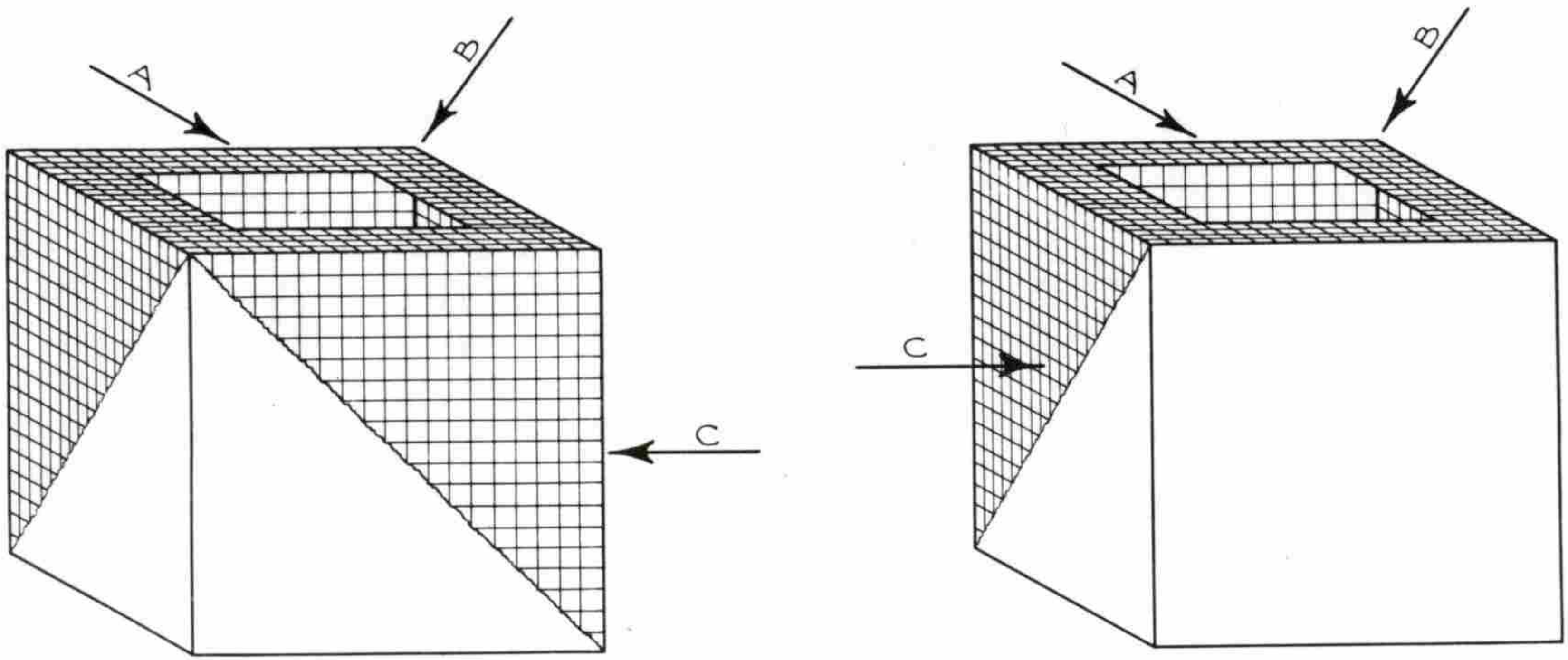
This condition will approximate exactly what happens when the wind blows from one direction for a long period of time. All of the smoke and soot will be directed against and through one end of the arrester. Quite naturally the arrester will soon become clogged on the side or end opposite the direction of the wind. Now, if the wind continues to blow the smoke and gases against the clogged side or end of the arrester, eddy currents of air and flue gases will be produced within the arrester and directly over the top of the chimney. Such eddy currents will tend to retard the flow of the gases and even cause a positive pressure in the chimney. If the wind should blow into the end of an arrester at an angle above the horizontal and against the opposite side or end which has become clogged, very serious trouble will be experienced. Table 24.

The test was repeated using wind direction B, Figure 45, for the arresters clogged in one and one-half of each side. Data for the test are recorded in Table 24. No noticeable effect was produced when the wind was in the side of the arrester, C, Figure 45. The data are not shown in the table.

TABLE 24

The Effect of Arresters Clogged in One End and One-half of Each Side upon the Available Draft in a Chimney When the Wind Velocity is 1400 ft./min.

Arrester Number	Draft in Inches of Water					
	No Wind	Wind at A	No Wind	Wind at B	No Wind	Wind at A 10° Above Horizontal
1	-.060	-.026	-.064	-.040	-.061	-.029
2	-.060	-.023	-.064	-.035	-.061	-.025
3	-.060	-.026	-.064	-.038	-.061	-.0
6	-.060	-.033	-.064	-.039	-.061	-.025
7	-.060	-.007	-.064	-.034	-.061	-.0
8	-.060	-.017	-.064	-.035	-.061	-.0



ARRESTER CLOGGED IN ONE CORNER

ARRESTER CLOGGED IN ONE END AND ½ OF BOTH SIDES

Fig. 45. WIND DIRECTIONS USED IN TESTING SPARK ARRESTERS

Results of test. An examination of the data in Table 24 indicates that side wind has a very serious effect upon the available draft in a chimney. When the wind was in direction A, Figure 45, and blowing directly into the clogged portion of the arrester, the available draft was reduced from -.060 to .007 inches of water when a No. 7 arrester was used. When the wind was in direction B, Figure 45, or at approximately 45 degrees to the end of the arrester, the results were not so critical; however, the available draft was reduced from -.064 to -.034 inch of water when a No. 7 arrester was used. The most critical condition was produced when the wind was in direction A but tilted into the top of the chimney 10 degrees above the horizontal. In this case the Nos. 3, 7 and 8 arresters reduced the available draft to 0. Such a condition is typical of what would happen if the chimney did not extend high enough above the ridge of the roof. Trees and tall adjoining buildings are likely to produce the same effect. Chimneys which are located at the end of a single story building which adjoins a double story building usually give trouble for the same reason.

The No. 6 arrester exhibited the least tendency to affect the available draft when the side winds were used. The reason for this was due to the fact that the arrester was made of expanded metal, the mesh of which was somewhat flatter and wider than the hardware cloth used in the construction of the rest of the arresters. The area of openings in the side of the arrester was slightly smaller than that found in the other arresters. The fact that this arrester showed up best in this particular test should not be taken as a decided advantage, because such an arrester exhibits a tendency to become clogged more quickly than those of other types.

The effect of partially clogged spark arresters upon the available draft in a chimney when there is a wind velocity of 1700 feet per minute blowing into the end of the arrester

After completing the test as previously described for a wind velocity of 1400 feet per minute, it was decided to continue the investigation by clogging the arresters only in one corner, Figure 46. This degree of clogging would not be so critical, yet it would be typical of the most common type of clogging and could occure after the arrester had been in use for only a very short while.

Equipment used in test. The equipment used in this test was the same as that previously described for the test using 1400 feet per minute wind velocity.

Testing procedure. The testing procedure was essentially the same as that previously described in the first test with side wind. However, after the test was completed the electric fan which furnished the side wind was placed so that it would force the wind at an angle of 45 degrees to the top of the

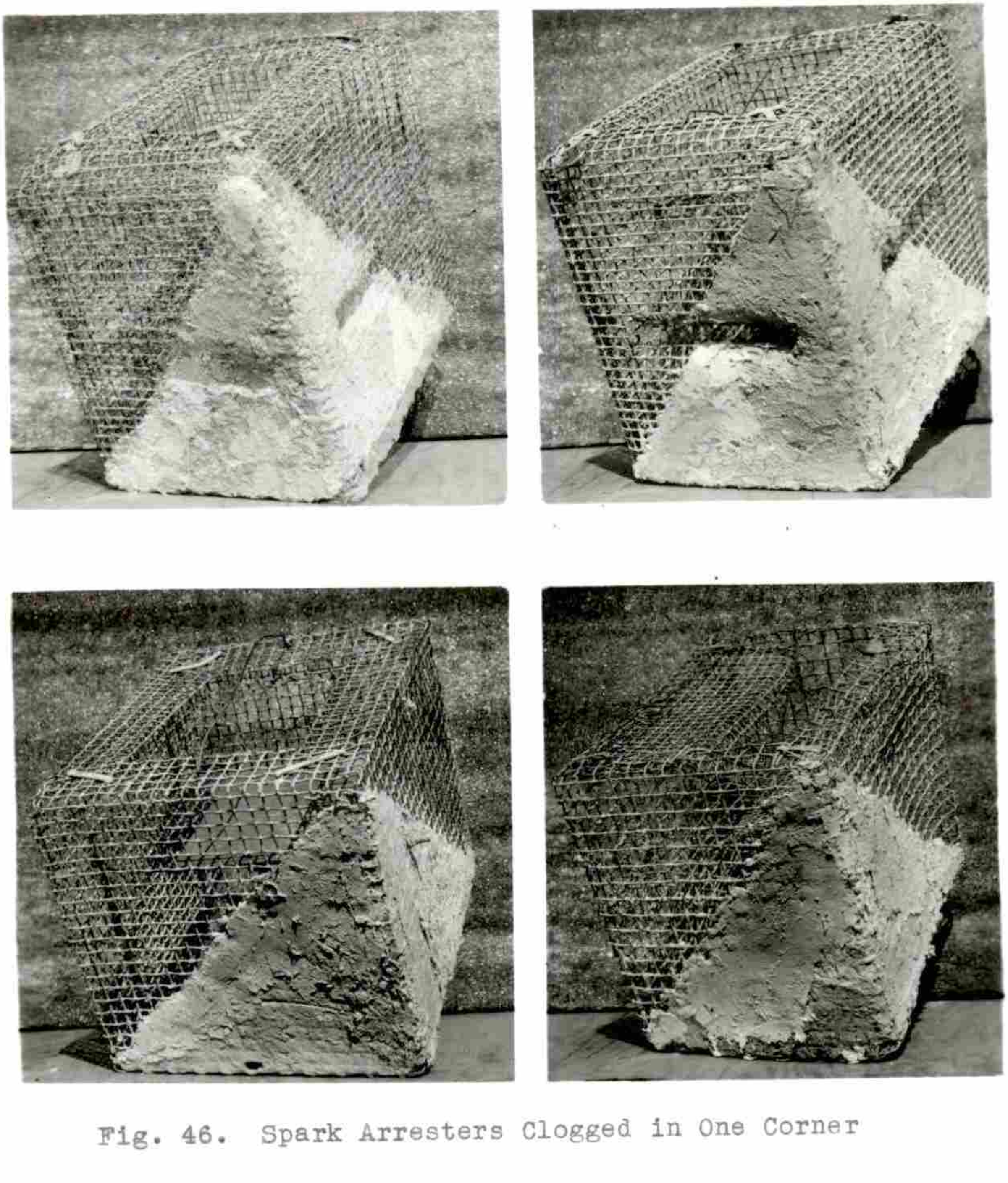


Fig. 46. Spark Arresters Clogged in One Corner

chimney. Such a direction of side wind would be duplicated by wind blowing up the slope of a roof and striking the top of the chimney.

Results of test. The data in Table 25 indicates that the arresters clogged only in one corner, Figure 46, have a decided effect upon the available draft in a chimney. In the test with wind at A, the available draft was reduced from -.057 to -.033 inch of water when a No. 7 arrester was used. When no arrester was used the draft was reduced only -.003 inch of water. There was not a great deal of difference in the results from different directions of wind in this series of test. However, the draft was reduced on the average of about 40 per cent for the wind at A, 40 per cent at C, and 43 per cent at B.

When the wind was blowing up the side of the chimney at an angle of 45 degrees the draft was not affected very much. Not more than -.003 inch of water difference in pressure was noticed.

The No. 3 arrester gave best results when the wind was at C. This may be attributed to the fact that the arrester has a very large cross-sectional area.

Discussion

Careful observations were made of the performance of the natural draft chimney discussed in the first preliminary test.

TABLE 25

The Effect of Spark Arresters Clogged in One Corner upon the Available Draft in a Chimney When the Wind Velocity is 1700 ft./min.

Arrester Number	Draft in Inches of Water					
	No Wind	Wind at A	No Wind	Wind at B	No Wind	Wind at C
1	-.057	-.037	-.061	-.038	-.059	-.040
2	-.057	-.037	-.061	-.041	-.059	-.030
3	-.057	-.034	-.061	-.040	-.059	-.052
6	-.057	-.037	-.061	-.034	-.059	-.041
7	-.057	-.33	-.061	-.035	-.059	-.020
8	-.057	-.035	-.061	-.041	-.059	-.040
Open	-.063	-.061	-.061	-.059	-.064	-.060

The results of the observation would be as follows:

1. Temperatures higher than 500 degrees Fahrenheit may be expected near the point where the breeching from the furnace enters the chimney. This would be true, especially during the winter months when the furnace is operated under a peak load. The temperature of the gases in the chimney may be regulated by controlling the amount of fresh air which is allowed to enter the chimney.

2. The draft is greatest near the bottom of the chimney and approaches atmospheric pressure at the top of the chimney.

In the tests using a kerosene heater the highest temperature recorded was 500 degrees Fahrenheit and the available draft at that instance was -.088 inch of water. Most of the tests were made while the maximum temperature in the chimney was around 300 degrees Fahrenheit. Under these conditions there was not a large quantity of gases to be carried from the chimney. As a result the spark arresters did not have any significant effects upon the performance of the chimney.

Summary and conclusions.

1. The effect of wind blowing into spark arresters which were clogged in one end and one-half of each side was investigated.

2. No. 7 arrester reduced the available draft in the chimney from -.060 to -.007 inch of water when the wind was

at A.

3. All of the arresters greatly reduced the available draft when the wind was blowing horizontally into the arrester from three positions.

4. Wind which strikes the top of the chimney or arrester at an angle above the horizontal causes the greatest effect upon draft.

5. Arresters which were clogged only in one corner affected the available draft considerably when there was a side wind blowing.

6. Wind blowing up the side of the chimney at an angle of 45 degrees did not produce a significant effect upon the available draft.

7. Careful observations during the testing and the test data will agree with the statement made by Stanworth (15), "In one way or other winds are the cause of at least 90 per cent of smoky chimneys."

8. The characteristics of a natural draft chimney were discussed.

9. Preliminary tests were made to study the characteristics of natural draft chimneys.

10. The effect of spark arresters upon the temperature, pressure and velocity of gases in a chimney was investigated.

11. The effect of spark arresters upon the flow of gases

in a chimney should be continued by using coal for fuel instead of kerosene.

SUMMARY AND CONCLUSIONS

Summary

1. A study of the effect of spark arresters upon the flow of gases in a chimney is justified by, (a) the number of spark arresters which have been installed; (b) the general criticism that spark arresters interfere with the draft in a chimney; and (c) the lack of information on the subject.

2. The objects of the study were to investigate the effect of partially clogged and completely clogged spark arresters upon, (a) the flow of air in model chimneys and (b) the flow of gases in a natural draft chimney.

3. The effect of spark arresters upon the static pressure and velocity of air flowing through two model chimneys was investigated.

4. The effect of spark arresters upon the available draft, temperature and velocity of gases in a natural draft chimney was investigated.

Conclusions

1. The results of the test, using partially clogged arresters on the small model chimney, were not very significant.

2. The small model chimney was not of unifrom cross-section and the rotation of the fan, together with the short

length of the pipe, produced pulsating flow of the air which gave considerable trouble.

3. When partially clogged spark arresters were tested on the large model chimney the velocity of the air in the chimney was reduced as much as 8.6 per cent when the 580 feet per minute velocity was used.

4. The pressure inside the chimney was constant throughout the height of the chimney when completely clogged spark arresters were used.

5. As the velocity of the air flowing through the large model chimney increased, the pressure readings also increased.

6. The clogged spark arresters greatly decreased the velocity of the air flowing through the arrester.

7. Air velocities of 425, 570, and 805 feet per minute, in the large model chimney, did not produce any significant differences in the per cent of the open chimney velocities.

8. Spark arresters Nos. 1, 2, 3, 4 gave best results throughout the tests using completely clogged arresters.

9. When the baffles in a No. 3 arrester were located 9 1/2 and 3 1/4 inches above the top of the chimney, the velocity of the air flowing through the chimney was greatly reduced.

10. The baffle in a No. 3 arrester should not be located above 9 1/2 inches or below 3 1/4 inches above the top of the chimney for best results.

11. The greatest negative static pressure in a natural draft chimney is at the bottom nearest the source of heat.

12. The static pressure varies considerably in a natural draft chimney.

13. The velocity of the flue gases fluctuates very widely in a natural draft chimney.

14. Wind blowing over the top of the chimney has a great influence upon the velocity of the flue gases and the available draft in a chimney.

15. The temperature in a natural draft chimney 24 feet above the furnace may exceed 220 degrees Fahrenheit when the chimney is operating under normal conditions.

16. Arresters Nos. 10 and 6 reduced the flow of gases in the chimney even though only a small quantity of gases had to be discharged and the velocity of the gases was very slow.

17. Very low velocities were encountered in the test using a natural draft chimney; as a result, the arresters which have a relatively large free area did not affect the flow of the gases.

18. Spark arresters which have a free area equivalent to the area of the chimney did not produce any significant effect upon the available draft in the chimney.

19. Spark arresters which were clogged in one corner or in one end and one-half of each side reduced the available draft in a chimney when there was a side wind blowing into

the arrester and against the clogged portion.

20. The flow of gases in a chimney is affected by, (a) temperature of the flue gases throughout the height of the chimney; (b) excessive friction; (c) insufficient height of the chimney; and (d) wind.

21. Further study is necessary in order to determine the effect of spark arresters upon the flow of gases in a chimney when a large volume of gases is flowing and with a chimney which is approximately 35 feet high.

22. No attempt will be made to compare the results of the tests using the model chimneys and the natural draft chimney, because of the fact that only very low velocities were encountered in the tests using a natural draft chimney.

LITERATURE CITED

1. American Society of Heating and Ventilating Engineers. Guide for 1937. p. 463-96. American Society of Heating and Ventilating Engineers, 51 Madison Avenue, New York. 1937.

2. Anon. Construction of chimneys and fireplaces. U. S. Dept. Agr. Farmers' Bul. 1649. 1937.

3. Anderson, Earl D. An analysis of Iowa's rural fire losses for 1930 and 1931. Unpublished thesis. Library, Iowa State College, Ames, Iowa. 1932.

4. Carpenter, Rolla C. Experimental Engineering, 5th Edition. p. 317-27. John Wiley and Sons, New York. 1902.

5. Giese, Henry. Investigations of domestic spark arresters. Unpublished report. Agr. Eng. Sect., Iowa State College, Ames, Iowa. 1938.

6. Hays, Jos. W. How to build up furnace efficiency. Jos. W. Hays, Rogers Park, Chicago. 1916. 154p.

7. Kratz, A. P. Use of draft gauge for chimney testing. Sheet Metal Worker. 17:321-22. Nov. 19, 1926.

8. Lanham, Frank B. The effectiveness of the domestic spark arrester in the control of roof fires.

Unpublished thesis. Library, Iowa State College, Ames, Iowa. 1936.

9. Mingle, J. G. Draft and capacity of chimneys. D. Van Nostrand Company, New York. 1925. 339p.

10. Morgan, William R. Condensation of moisture in flues. p. 17-20. Ill. Agr. Exp. Sta. Cir. 22. 1934.

11. National Board of Fire Underwriters. A standard ordinance for chimney construction. p. 166-79. Nat. Bd. Fire Underwriters, 85 John St., New York. 1927.

12. Peach, Charles E. The construction and tests of a new form of screen spark arrester. Unpublished report. Agr. Eng. Sect., Iowa State College, Ames, Iowa. 1937.

13. Peikert, Frank W. Prevention of roof fires by the use of spark arresters. Unpublished thesis. Library, Iowa State College, Ames, Iowa. 1934.

14. Price, David J. Rural losses $225,000,000 yearly. Volunteer Fireman. 4:5. Dec. 1937.

15. Stanworth, James. Smoky chimneys and the study of air currents. Crosby Lockwood and Son, London. 1930. 46p.

16. Test, William D. The behavior and control of soot particles during a chimney burn-out. Unpublished report. Agr. Eng. Sect., Iowa State College, Ames, Iowa. 1936.

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